

VOLUME II TECHNICAL
BOOK 1 OF 5

by

Thiokol / WASATCH DIVISION
A DIVISION OF THIOKOL CHEMICAL CORPORATION

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

George C. Marshall Space Flight Center

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FINAL REPORT

STUDY OF SOLID ROCKET MOTOR
FOR SPACE SHUTTLE BOOSTER

VOLUME II TECHNICAL
BOOK 2 OF 5

by

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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George C. Marshall Space Flight Center
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PREFACE

This report contains the results of Thiokol Chemical Corporation's Study of Solid Rocket Motors for Space Shuttle Booster. The objective of the study was to provide data to assist National Aeronautics and Space Administration in selection of the booster for the Space Shuttle system. This objective was satisfied through definition of specific Solid Rocket Motor (SRM) stage designs, development program requirements, and production and launch program requirements, as well as the development of credible cost data for each program phase. The study was performed by Thiokol's Wasatch Division, Brigham City, Utah, for the NASA George C. Marshall Space Flight Center under Contract NAS 8-28430. The study was conducted under the direction of Mr. Daniel H. Driscoll/PD-RV-MGR NASA/MSFC. Thiokol study direction was provided by Messrs. E. R. Kearney, Corporate Director, Space Shuttle Program, and J. D. Thirkill, Program Manager, Space Shuttle SRM Booster Study, Wasatch Division

The final report was prepared in response to Data Procurement Document 314 and Data Requirement MA-02. The report is arranged in four volumes:

- Volume I - Executive Summary
- Volume II - Technical
- Volume III - Program Planning Acquisition
- Volume IV - Cost

Data Requirement M. -02 specified that the Cost report be part of the Program Acquisition and Planning report but because of its importance and size it has been bound as a separate volume in this Final Report.

Volume II, Technical, has been further subdivided into five books as follows for ease of review and handling:

Book 1

- Section 1.0 - Introduction
- Section 2.0 - Propulsion System Definition
- Section 3.0 - SRM Stage

Book 2

- Section 4.0 - SRM Parametric Data**
- Section 5.0 - SRM Stage Recovery**
- Section 6.0 - Environmental Effects**
- Section 7.0 - Reliability and Failure Modes**
- Section 8.0 - System Safety Analysis**
- Section 9.0 - Ground Support Equipment**
- Section 10.0 - Transportation, Assembly, and Checkout**

Book 3

- Appendix A - Systems Requirements Analysis**

Book 4

- Appendix B - Mass Property Report**
- Appendix C - Stage and SRM CI Specifications**
- Appendix D - Drawings, Bill of Materials, Preliminary ICD's**

Book 5

- Appendix E - Recovery System Characteristics for Thiokol Chemical Corporation Solid Propellant Space Shuttle Boosters**
- Appendix F - Quantitative Assessment of Environmental Effects of Rocket Engine Emissions During Space Shuttle Operations at Kennedy Space Center**
- Appendix G - Thiokol Solid Propellant Rocket Engine Noise Prediction**
- Appendix H - SRM Stage Recovery**

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4.0 SRM PARAMETRIC DATA

4.0 SRM PARAMETRIC DATA

The 156 and 260 in. SRM baseline designs chosen by Thiokol for use on the Space Shuttle were designed for a maximum expected operating pressure (MEOP) of 1,000 psia; the 120 in. motor has an MEOP of 800 psia. The following curves, Figures 4-1 , 4-2 , and 4-3 , compare the baseline designs at their design MEOP and also at 750 psia. The comparisons presented show that the baseline cases are not the optimum condition for each motor. A more comprehensive parametric and optimization study must be conducted that will take into consideration interactions of motor pressure and other motor parameters.

The composite plot of mass fraction vs propellant weight presented in Figure 4-4 for the three diameters indicates that each motor size has an optimum propellant weight-mass fraction relationship.

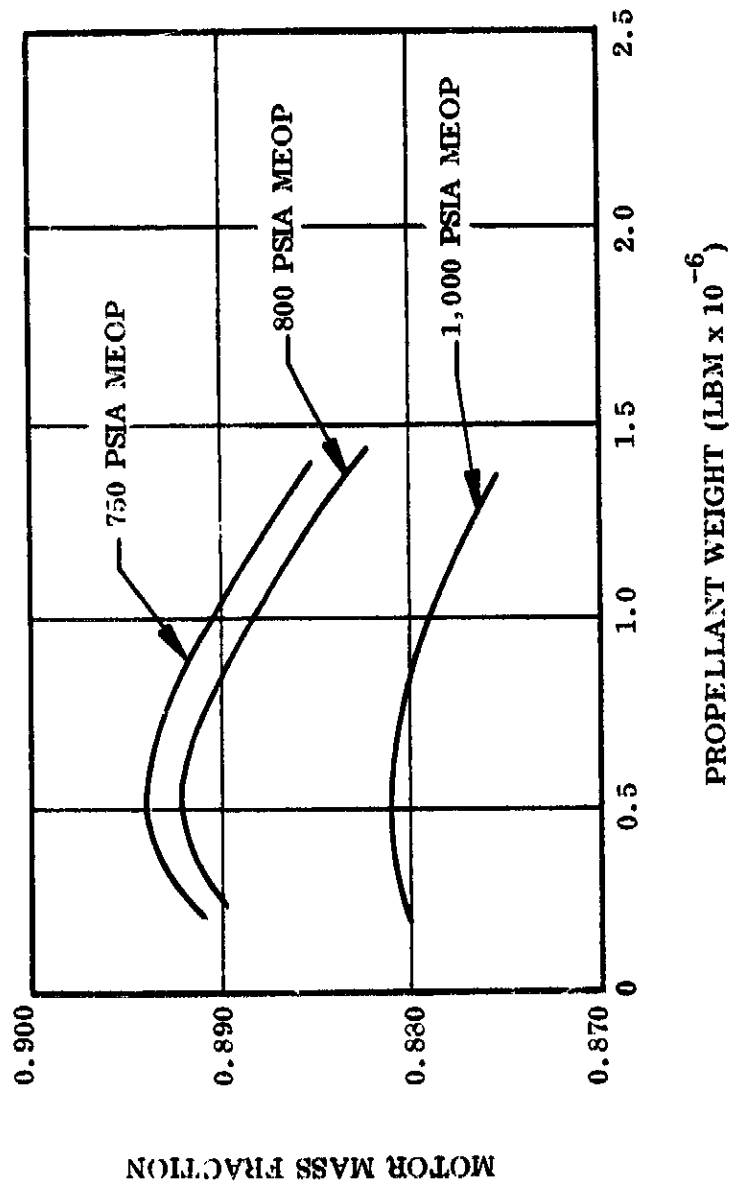
Figure 4-5 is presented as a comparison of motor lengths and propellant loadings. The figure also indicates the L/D ratio where L is the total length of the motor case and D is the outside diameter of the case. An L/D of 10 is approximately the maximum practical limit. Motors with a larger L/D could be constructed, but propellant loading would decrease, and the motor mass fraction would thus be lower than optimum.

The growth potential for the large solid rocket motors is limited only by the availability of equipment and facilities to handle them. As pointed out earlier, each diameter SRM has an optimum propellant loading configuration; however, as motor diameter is increased, the peak of the mass fraction-propellant weight curve becomes progressively flatter, indicating that the larger motors have a wider band in which motor mass fraction is an acceptable value. For 120 in. motors, the practical motor size ranges from approximately 0.25 to 0.7 million lb of propellant with a corresponding length of 400 to 1,200 in. The 156 in. motor has a wider range in the practical limits of 0.5 to 1.6 million lb of propellant where the lengths are 250 to 1,600 in. The obviously wider range in practicality for the 260 in. motor is 1.5 to approximately 6 million lb of propellant and 500 to 2,600 in. in length.

PARAMETERS:

PROPELLANT = PBAN

BURN TIME = 135 SEC



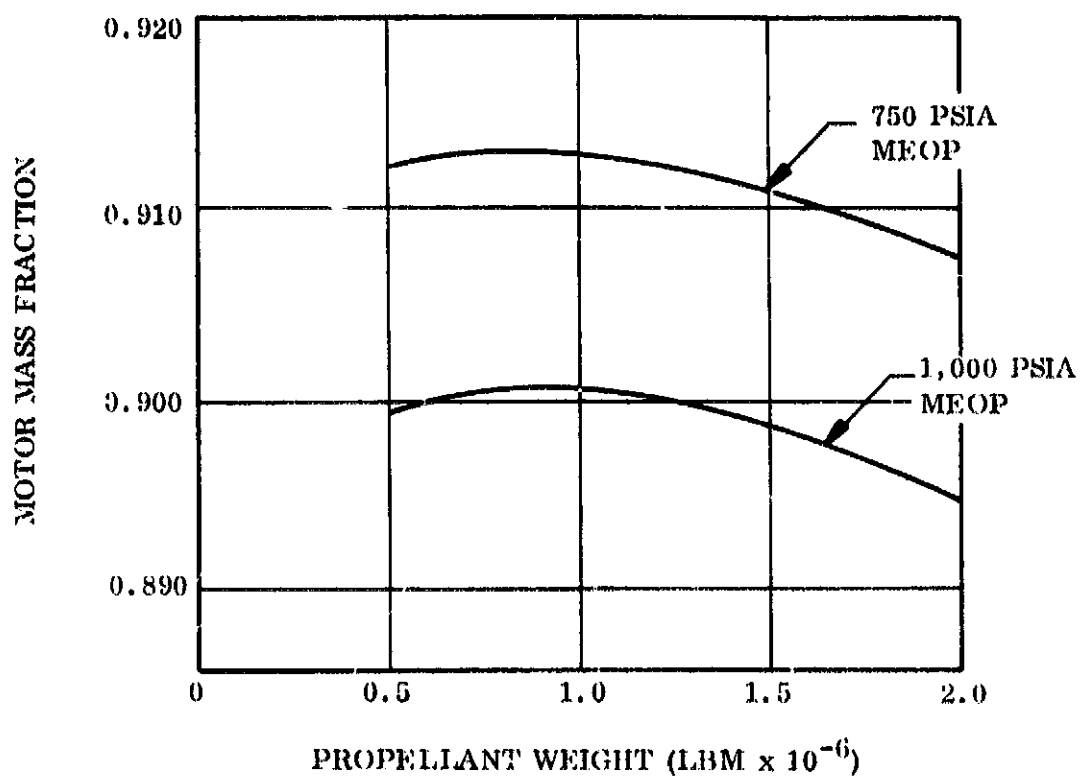
36175-6

Figure 4-1. Motor Size - Mass Fraction Comparison for 120 in. Diameter SRM

PARAMETERS:

PROPELLANT = PBAN

BURN TIME = 135 SEC

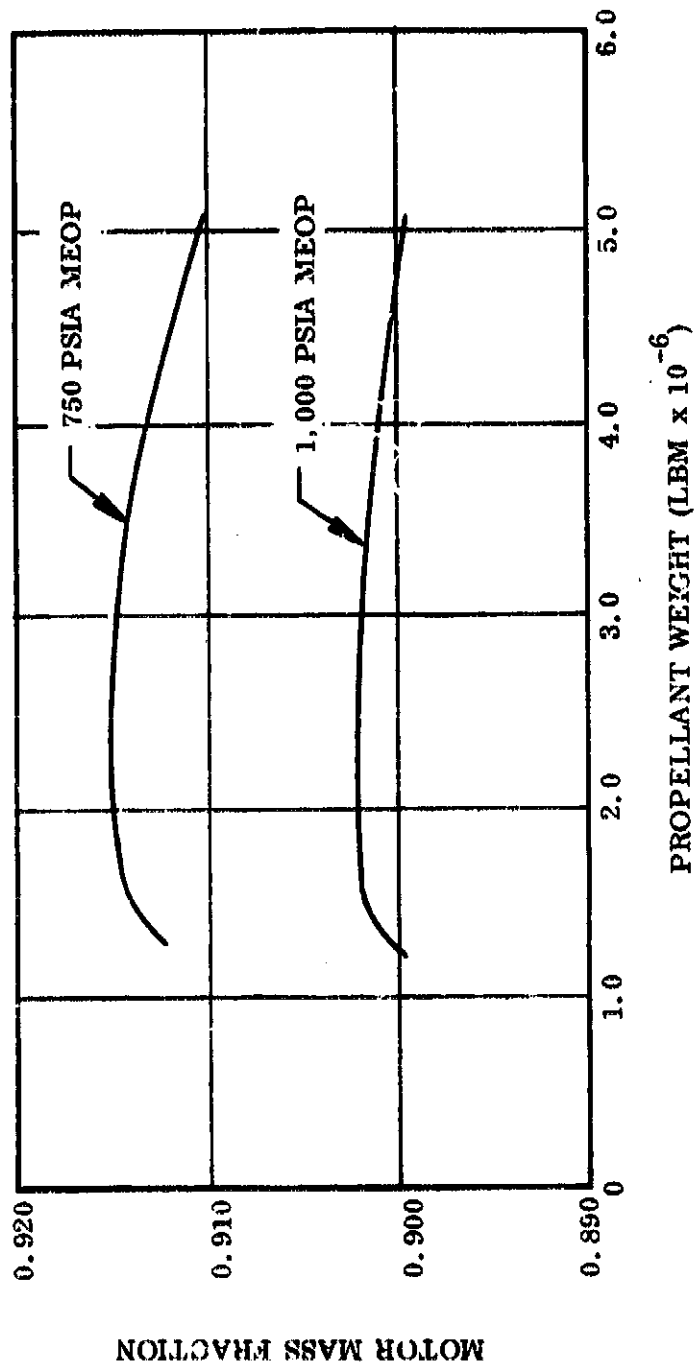


36175-7

Figure 4-2. Motor Size - Mass Fraction Comparison for 156 in. Diameter SRM

PARAMETERS:

PROPELLANT = PBAN
BURN TIME = 135 SEC



36175-5

Figure 4-3. Motor Size - Mass Fraction Comparison for 260 In. Diameter SRM

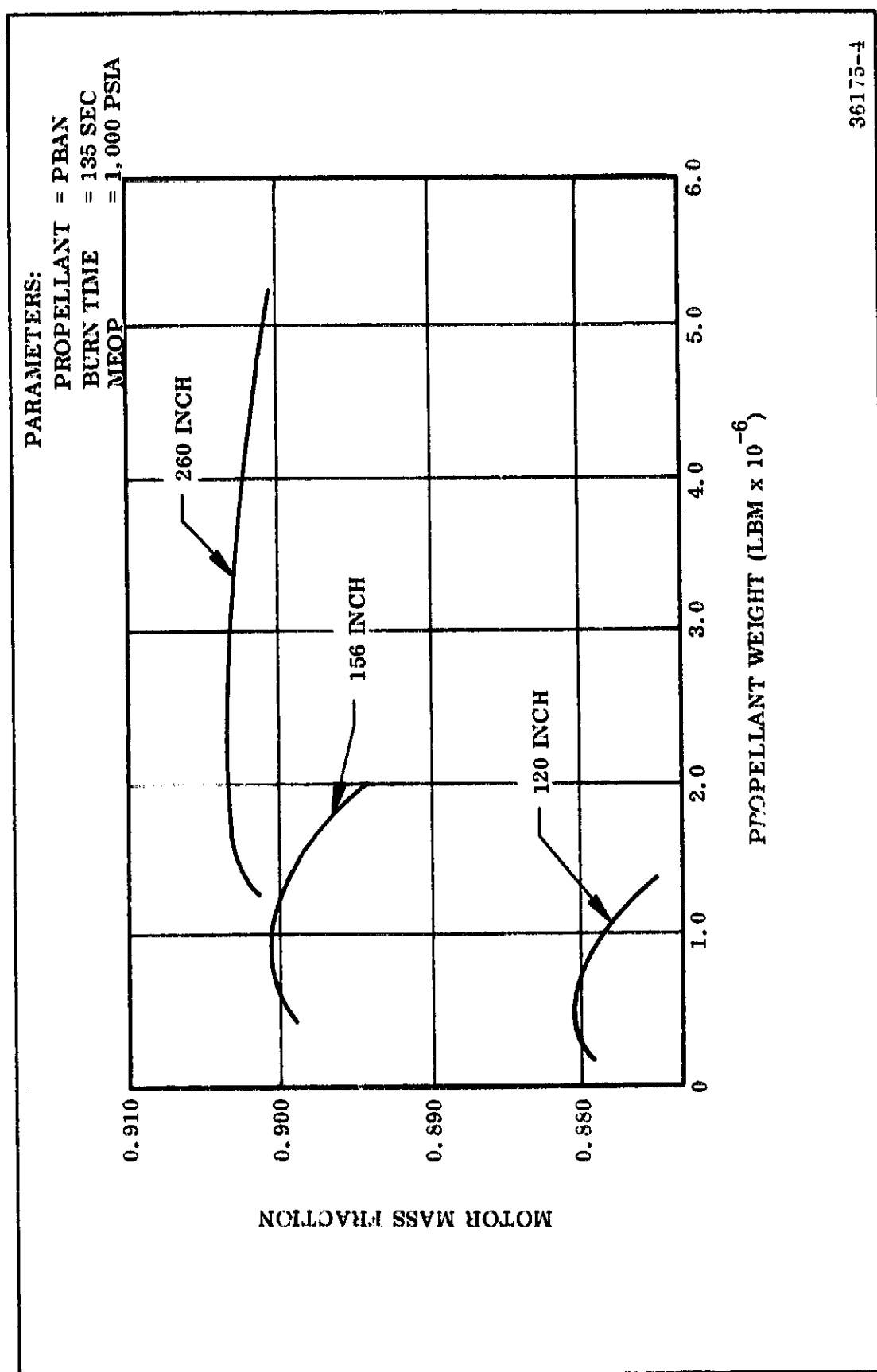
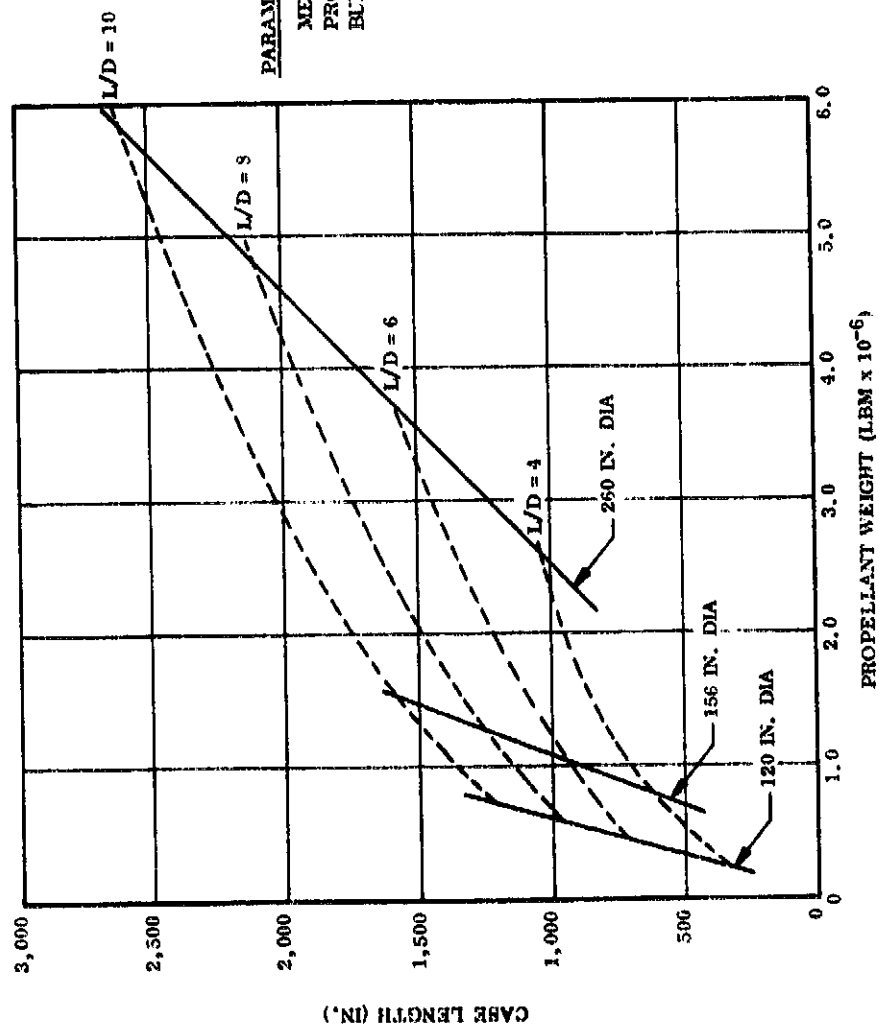


Figure 4-4. Motor Size - Mass Fraction Comparison for 120, 156, and 260 In. Diameter SRM's



PARAMETERS:
 MEOP = 1,000 PSIA
 PROPELLANT = PRAN
 BURN TIME = 135 SEC

36175-72

Figure 4-5. Motor Size Comparison for Large SRM's

5.0 SRM STAGE RECOVERY

An investigation of recovering the expended solid propellant Space Shuttle booster was conducted. This feasibility study included descent dynamic modes, anticipated design loads, effects of sea impact, and additional onboard hardware required for the recovery system. The additional recovery hardware components were sized, cursorily designed, and evaluated. Those rocket motor hardware components considered for refurbishment are delineated.

Preliminary investigations serve to substantiate complete feasibility of SRM recovery. Additional investigation is required to fully characterize the loading environment and load capability of the SRM Stage; however, the anticipated problems should readily yield to solution through minor case design modifications and control of the sea impact conditions.

The SRM recovery system must return the spent SRM stage after it has served its propulsive usefulness without damaging the SRM case. The spent SRM case will be retrieved at sea and carried by ship to a dock facility.

The descent trajectory of the spent SRM case can be separated into three phases: (1) atmospheric reentry, (2) supplemental device deceleration, and (3) water impact.

The booster motors are jettisoned from the Space Shuttle at a maximum altitude of 160,000 ft traveling with a maximum velocity of about 6,000 fps and must then be slowed during the reentry phase. Since the flight regime is hypersonic, parachute or cloth deceleration devices are not acceptable because of the associated aerodynamic heating and flow field problems. Therefore, it is desirable after stage separation to orient the booster in a broadside attitude for reentry to develop a high drag condition slowing the booster vehicle sufficiently for deployment of parachutes. Two methods of attaining the broadside reentry are: (1) letting the cylindrical body tumble in an autorotation mode, or (2) using balanced dihedral fins to cause the booster to assume a nearly 70 deg angle of attack during the transitional flight period.

5.1 AUTOROTATION MODE

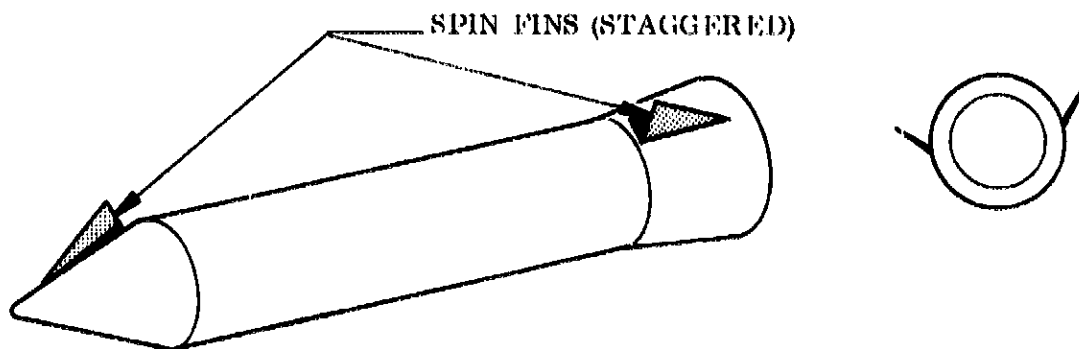
The descent velocity of a body can be reduced by initiating a flat spinning motion such that the body continuously presents a large fraction of its maximum projected area to the free stream. Because of the large increases in both the drag area and the drag coefficient as the angle of attack is increased to near 90 deg, the deceleration at a very large angle of attack can be many times greater than that of the same body in normal stable flight at a small angle of attack.

Autorotative spinning (or yawing) motion is a means by which a large angle of attack can be developed and sustained. Large angles of attack cannot be sustained unless the aerodynamic center of pressure is nearly coincident with the center of gravity. The expended SRM configuration closely approximates a cylinder with the center of gravity and the center of pressure nearly at the centroid of the planform area.

If the empty booster reenters in a tail-first attitude, it will remain at 180 deg angle of attack; ie, nozzle first, because this is the stable trim angle for the basic center of gravity. This type of attitude is called the bomb mode. At this angle of attack the booster drag is a minimum and the $\alpha = 180$ deg reentry trajectory will result in the largest values of the maximum dynamic pressure.

If the booster reenters at an angle of 90 deg and without roll, spin, or yaw rate, a tumbling motion will be initiated due to the aerodynamic overturning moment. The tumbling motion will persist until a peak oscillation amplitude is attained. The body will then oscillate with decreasing amplitude, due to both the aerodynamic damping and hetero-parametric damping associated with increasing dynamic pressure. The motion will eventually damp to the stable trim angle of 180 deg. If the booster also has a small axial spin, the oscillations will be smaller in amplitude, but the booster will still rotate and eventually reach the 180 deg angle of attack condition. Since these tumbling reentries, as well as the tail-first reentry, are possible for a passive type, nonyawing reentry, rotation in the yaw plane must be induced to the body to assure the 90 deg angle of attack reentry.

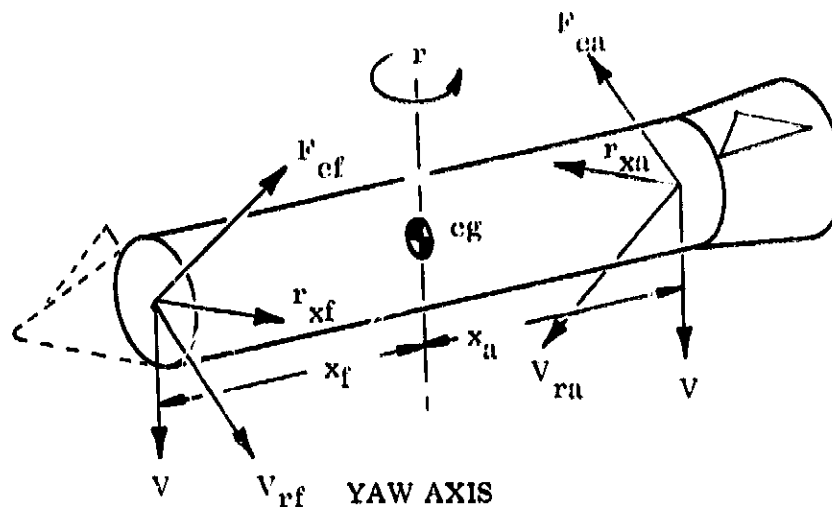
To cause autorotation motion at supersonic speeds, a body-fixed lifting surface must be attached to the expended rocket case as shown in the sketch below.



The lift generated by a longitudinal fin will produce an autorotative moment* by causing the local resultant cross force vector to be inclined relative to the descent

*Brunk, James E., "The Dynamics and Aerodynamics of Self-Sustained Large Angle of Attack Body Spinning Motions," AFOSR-4596, February 1963.

velocity vector. Thus, a force component results that is in a plane normal to the descent velocity vector. This force, acting at a distance from the body center of gravity, produces a moment inducing rotation in the yaw plane.



- | | |
|--|---|
| V - free stream velocity at cg | F_{cf} - resulting aerodynamic force at fwd tip |
| V_{rf} - free stream velocity at fwd tip | F_{ca} - resulting aerodynamic force at aft tip |
| V_{ra} - free stream velocity at aft tip | $\dot{\alpha}$ - yawing angular rate |

The problem with inducing the spent booster into the yawing autorotative spin is that it must be despun prior to main parachute deployment. The method proposed to despin the body is to deploy a carefully designed drogue similar to those used to despin supersonic aircraft during emergency conditions.

Two small triangular-shaped fins; one located near the forward attach structure and a second located near the aft attach structure will provide enough fin surface to initiate and sustain the autorotation mode of spinning.

Thiokol has observed this autorotative spinning on the LUU-2/B illumination flare ordnance hardware. This flare is finless and as initially deployed it is configured as a smooth right circular cylinder 36 in. long and 5 in. in diameter. The center of gravity of this flare is less than 2 in. from the geometric center. When dropped from an aircraft, the cylinder tumbles end over end, damps out at near 90 deg angle of attack, and then transitions into the autorotative spin mode. Spin rates of up to 700 rpm have been observed. Further analysis of the SRM may indicate that this spent rocket stage may go into the autorotative mode without the fins or covered attachment fairing.

A detailed analysis of the required fin size will need to be considered relative to other associated problems. The projected fin or covers may cause deleterious effects on the rocket case at water impact.

The fin size to cause and sustain autorotation is closely related to (1) the distance between the body center of gravity and aerodynamic center of pressure at 90 deg angle of attack, (2) body symmetry about the cg, (3) the body fineness ratio, and (4) the free stream velocity.* The closer the cg-cp relationship the smaller the fins. The more symmetrical about the cg, the smaller the fins, the lower the fineness ratio the smaller the fins, and the lower the free stream velocity the smaller the fins. The empty parallel booster descent is favorable with respect to items (1) and (2), and unfavorable with respect to items (3) and (4). The cg-cp distance is calculated to be 30 in.; ie, 0.02 of body length. The body is nearly a right circular cylinder and the center of gravity is nearly in the center; ie, 0.56 of body length. The booster L/D ratio is about 10 and the terminal velocity will be about $M = 1.2$.

Preliminary sizing of the autorotation fins for this body indicates that small fins are required. Figure 5-1 presents the fin geometry and their location on the booster. Note that the fins are located equal distance from the center of gravity to minimize their effect on the pitching moment. The forward fin will be attached to the rocket motor forward dome segment skirt stub and the aft fin will be attached to the aft skirt structure. The fins are dihedral with respect to the booster and are located radially 180 deg apart. This fin configuration should assure near zero bank angle, ie, the body will be at a roll attitude such that the same side of the case is always directed towards the air stream. At zero bank angle and equal rotational lever arm, the forward and aft fins should see the same flow field, thus yielding a balanced autorotational yawing moment.

5.2 BALANCED DIHEDRAL FINS

The alternate approach is to use balanced dihedral fins for reentry. These control fins would be mounted on the aft skirt to control the vehicle attitude during reentry of the spent SRM. These fins would be sized to orient the case at or near 70 deg angle of attack. At this high attitude, relatively high resultant forces will cause the velocity to decrease to a level which will allow deployment of a deceleration parachute prior to water impact.

These aerodynamic control fins, because of their size, would be heavy, complex, and costly. Such an attitude control system would require hydraulic actuators, servovalves, hydraulic and electrical power supplies, and a fairly complex autopilot.

Because of the technical aerodynamic problems and the associated wind tunnel testing, control system, and hardware costs, the concept of flying the empty case in during reentry is not seriously considered as a method of controlling the descent.

*Brunk, J. E., Davidson, W. L. and Rakestraw, R. W., "The Dynamics of Spinning Bodies at Large Angles of Attack," AFOSR/DRA-623, January 1962.

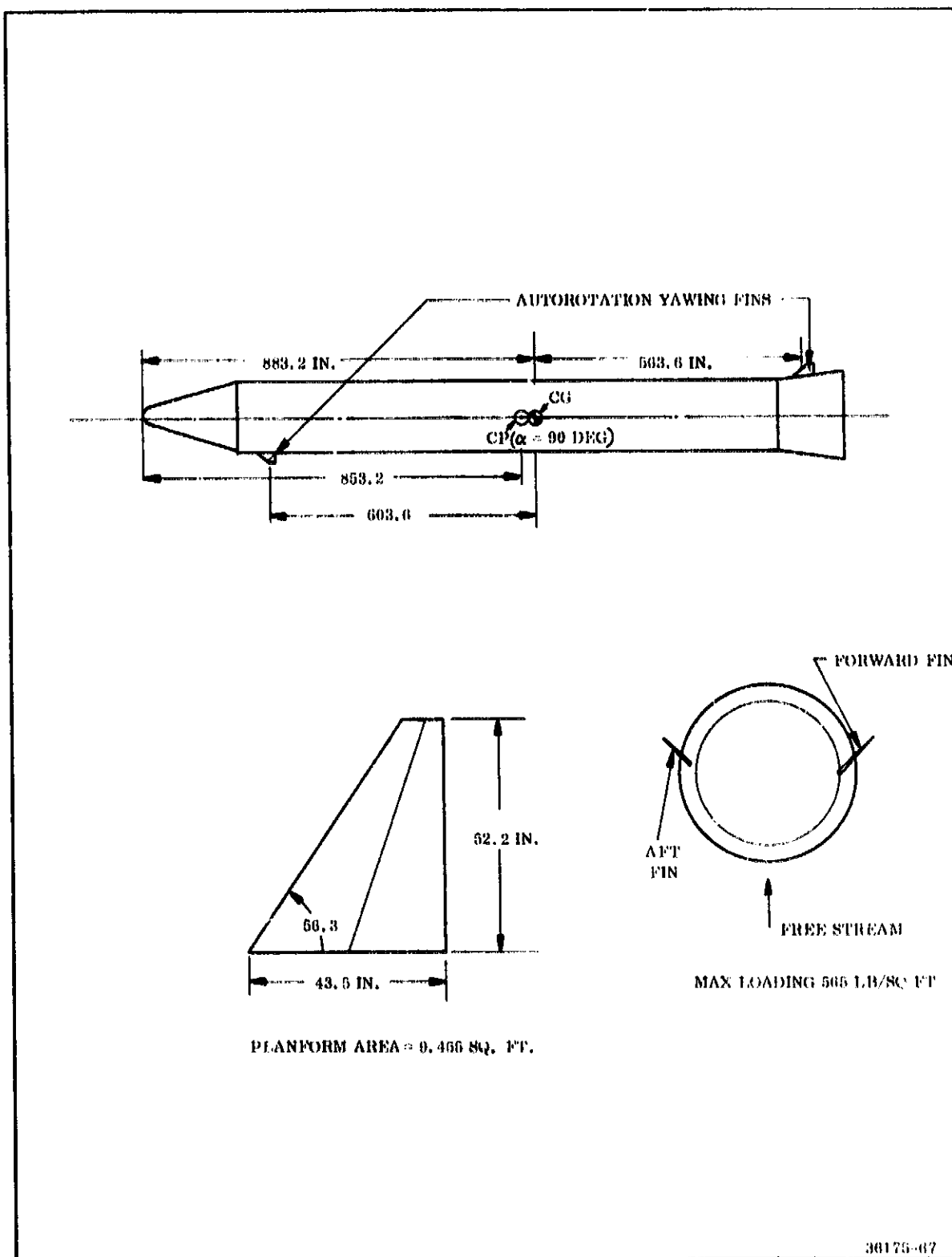


Figure 5-1. Autorotation Fin Geometry and Location

5.3 BOMB MODE

An alternate method of recovering the booster is to let the booster stage tumble and eventually damp out at 180 deg angle of attack in the bomb mode. The vehicle will approach a terminal velocity traveling nearly Mach 1.6 at 20,000 ft altitude. Larger and stronger drogue chutes, or possibly a drogue chute system similar to those used on special weapons, could be deployed to decrease the stage velocity to that at which the main parachute could be safely deployed.

Historically, supersonic deceleration systems have been expensive to develop and have imposed severe weight penalties. To design such a system, detailed studies will be required to define (1) how the unfinned SRM Stage tumbles and in what dynamic mode, and (2) magnitude of the rotation rates at drogue deployment.

5.4 DECELERATORS

Preliminary trajectory investigations indicate that during a broadside re-entry, the booster case temperature will increase 200°F due to aerodynamic heating. The maximum dynamic pressure will be less than 450 psf and will occur near 90,000 ft altitude. Thus, the thermal and aerodynamic loads on the parachute compartment are negligible during re-entry.

Recovery gear must include devices to provide tracking and locating signals for hardware pickup. These location aids would include a radio beacon to track the spent boosters at high altitude, smoke generating flare aid in the parachute descent phase and dye marker, flashing lights, or illuminating flares for sea locators.

The parachute for deceleration prior to water impact will be initiated near 20,000 ft altitude. The SRM Stage velocity will be approximately $M=1.2$ and be oriented at a -40 deg flight path angle. A mortar-fired pilot chute will be required to deploy the drogue chute. The drogue chute will be of reefed ribbon design and when fully deployed will despin the vehicle, bring it to near vertical attitude, and slow it to about 900 fps in the reefed condition. At 15,000 ft altitude the main parachutes will be deployed initially in the reefed condition, slowing the vehicle to 236 fps. At 12,000 ft altitude, the main parachutes will be disreefed and slow the booster to the desired impact velocity of 100 fps. Vehicle attitude at water impact will be at near vertical. The parachute will detach at water impact. Figure 5-2 depicts the above mentioned sequence.

The parachutes will be packaged inside the aft skirt between the nozzle and skin fairing as shown in Figure 5-3. Deployment of the deceleration device will be controlled by a barometric device.

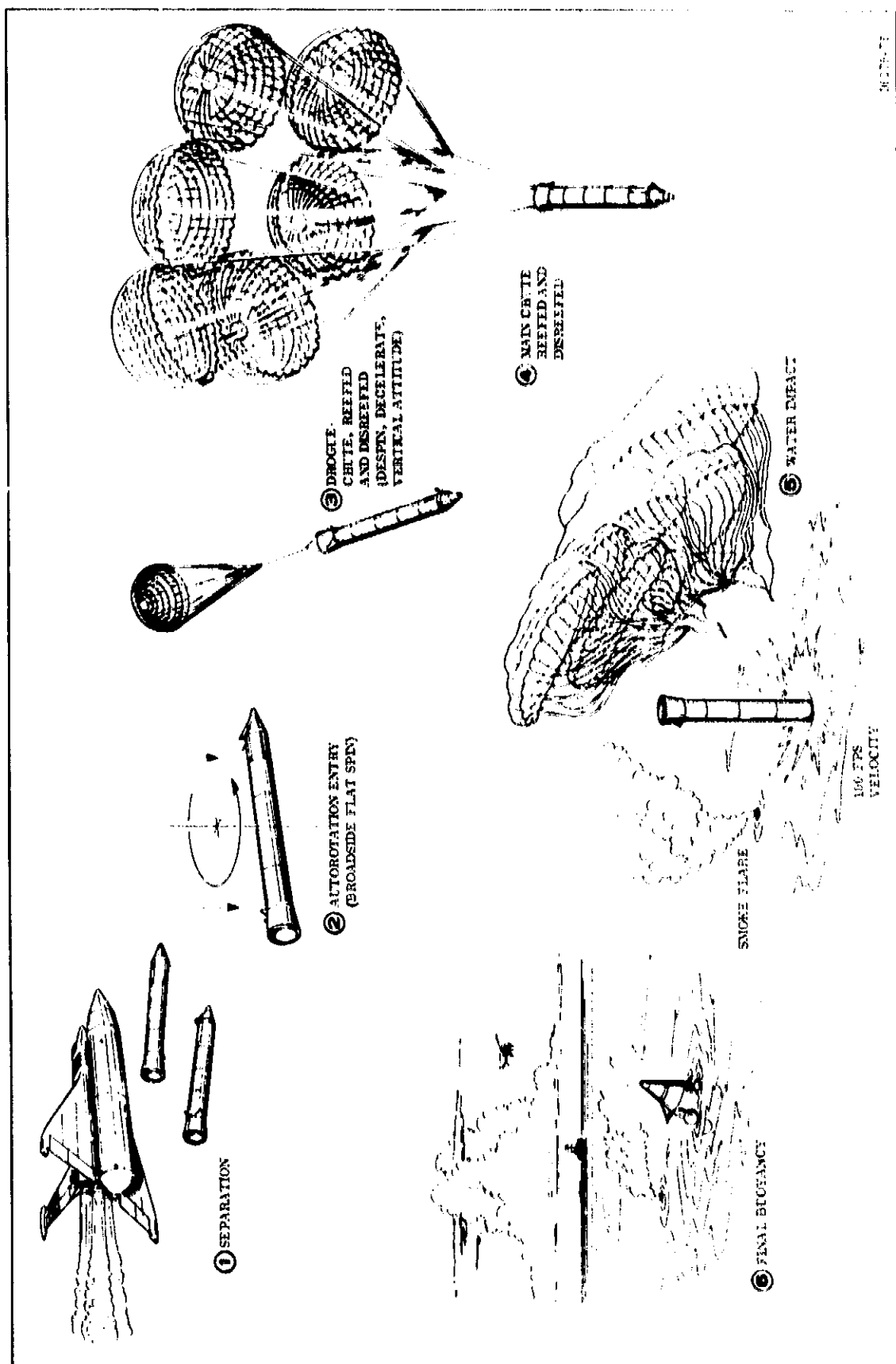


Figure 5-2. Recovery Parachute Deployment Sequence

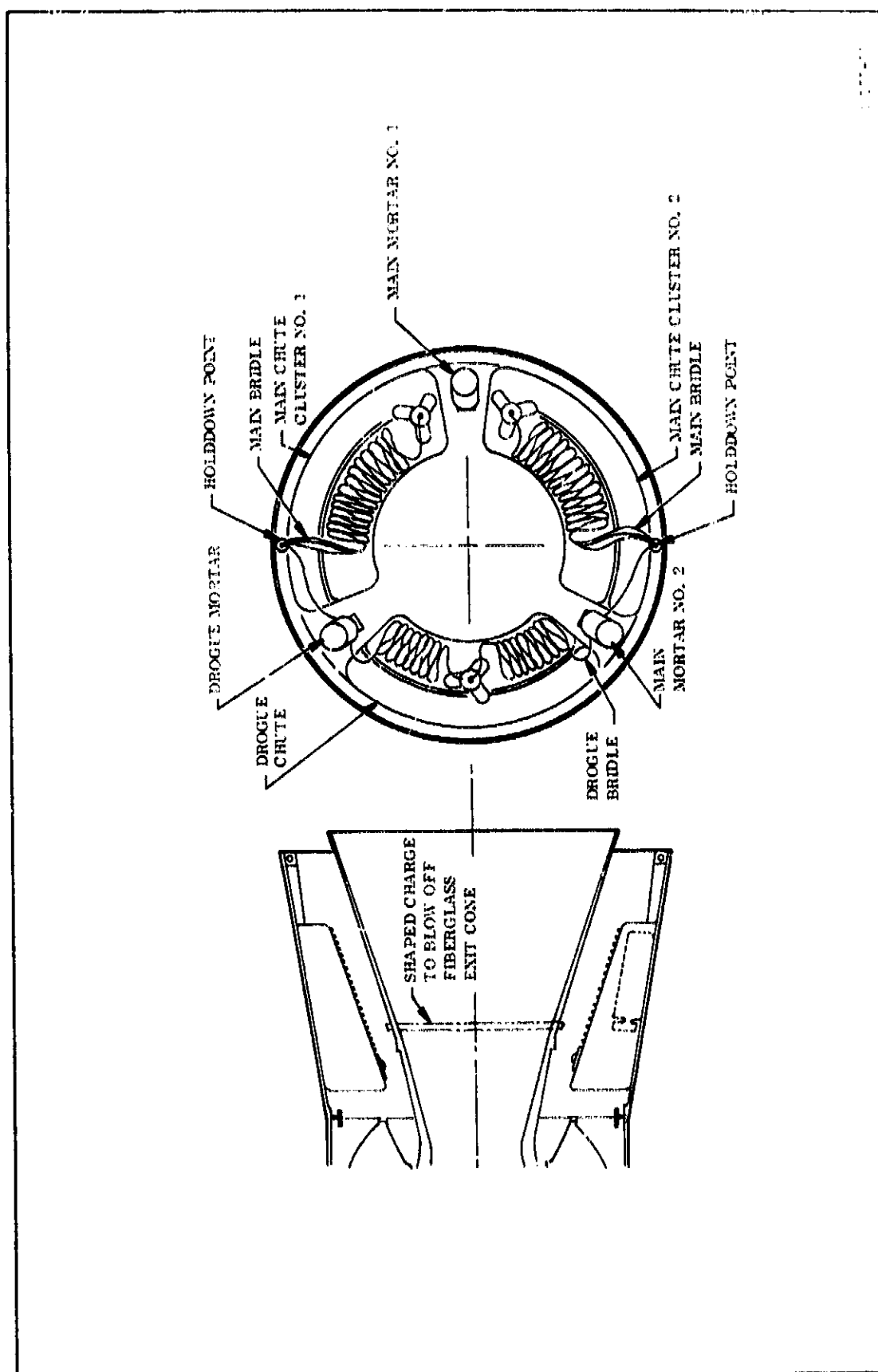


Figure 5-3. Recovery Parachute Stowage

Goodyear Aerospace Corporation was awarded a subcontract by Thiokol to study, size hardware, and estimate costs for a parachute recovery system for the Space Shuttle SRM. Their report is included as Appendix E. They investigated decelerator systems for 50, 100, and 150 fps splashdown requirements for both the single parallel motor and the series cluster. Their hardware recommendation for the 100 fps criteria for the parallel configuration includes the following components for which a detail weight breakdown is tabulated in Table 5-1 .

Drogue Pilot Mortar (4.7 lb/one required)--The mortar-deployed pilot chute is required to expel the squided canopy free of the aerodynamic wake caused by the primary body. The device is a stainless steel container 13.2 in. in diameter and 39.6 in. long. Pressurization is supplied by a solid propellant gas generator power unit mounted on the forward end of the canister. A sabot piston with an O-ring seal fits between the power unit and the pilot chute. The sabot piston does not allow the warm gases to pass by and damage the pilot chute. When the gas generator charge is ignited, the gases push the sabot piston and the packed pilot chute out of the aft end of the tube at a velocity of 105 fps.

Drogue Pilot Parachute (20 lb/one required)--This chute, attached to a long riser line, will be ejected into the quiescent free stream. The purpose of this parachute is to extract the high speed drogue from its canister. This chute will be a 9 ft diameter ribbon type, and will pull the drogue chute package out with a maximum load of 10 gs.

Drogue Parachute (2,330 lb/one required)--The drogue chute will despin the tumbling booster and slow it to a velocity at which the main parachute system can be safely deployed. This chute is designed to be deployed at Mach 1.2 at 20,000 ft altitude. It is a high strength, 40 ft diameter ribbon parachute. This chute will have single stage reefing and will sustain a 2.9 g shock opening load, which corresponds to a maximum load of 435,000 lbf.

Drogue Riser (357 lb/one required)--The drogue riser is 27 ft long and made of nylon.

Main Pilot Mortars (48.5 lb/two required)--These sabot devices are similar to the drogue pilot mortars. They are 13.8 in. diameter and 41.6 in. long. They eject the main pilot parachutes at a velocity of 105 fps.

Main Pilot Chute (45 lb/two required)--The main pilot chutes will pull out the package composed of three each main parachutes. These chutes will be of ribbon design, 19.6 ft in diameter and will exert a maximum of 10g's acceleration on the main chute cluster package.

NOTE: The drogue chute cannot be used as the pilot chute because the main chutes are in two separate packages.

TABLE 5-1

**WEIGHT OF RECOVERY SYSTEMS FOR 100 FPS
WATER IMPACT VELOCITY**

Main parachutes (six 81 ft dia ribbon)	3,873
Drogue parachute (40 ft dia ribbon)	2,330
Main riser bridle	291
Drogue riser bridle	357
Sequencer, reefer cutter, bags, confluence rings, misc	1,000
Pilot chute (drogue)	20
Pilot chute (main)	90
Main riser bridle	144
Drogue riser bridle	88
Drogue mortar	47
Main mortar	<u>97</u>
	8,337
Attachment and compartment structure	1,000
Inflation system	
Orientation system	130
Main chute flotation	90
Drogue flotation	<u>18</u>
	238
Beacon and flashing light/smoke flare	<u>122</u>
Subtotal	9,697
Contingency	<u>1,314</u>
Total for each SRM	11,011
Stage total	22,022

Main Pilot Riser (72 lb/two required)--These risers are 75.6 ft long and will place the main pilot chutes out far enough so that each can pull out its attached main cluster package without interfering with the other.

Main Parachutes (645.5 lb/six required)--The main parachutes will be deployed at about 15,000 ft where vehicle velocity is 540 fps. These chutes will have single stage reefing and be configured in two clusters of three. These fairly lightweight chutes will be an 81 ft diameter ribbon type design.

Main Parachute Riser (291 lb/one required)--The main parachute riser includes a bridle system that separates the two parachute clusters. The main parachute riser/bridle system is anchored to the pad holddown points on the SRM aft skirt structures.

Orientation Device (130 lb/one required)--The orientation device system is designed to rotate the booster after it is lying in the water to one of four roll positions. In each of the four positions a radio beacon and a flashing light will be visible from any approach direction. Positioning is accomplished by inflating four rows of inflatable spheres attached to the outside of the booster. The rows are located 90 deg apart around the circumference. The locating beacon and light are 180 deg apart from each other. The beacon and light are each 45 deg from two of the rows of spheres.

Preliminary calculations indicated the waterline will be 2.5 ft up from the bottom of the cylindrical part of the booster and the booster will lie nearly fully exposed and level in the sea.

The number of spheres specified for this system will prevent the booster from rolling over in a Sea State Four condition.

5.5 PARACHUTE STOWAGE

For proper deployment, the parachutes must be located so they can be extracted from the suspended body in nearly a straight line to the final inflated position. Because the water entry mode is nose first, the parachute compartment must be located on the aft end of the rocket motor and the deployment will be directly aft. A compartment aft of the hydraulic control system hardware between the aft skirt and the nozzle exit cone (Figure 5-3) has been tentatively selected. To use this location, the nozzle exit cone must be removed prior to parachute deployment. The exit cone is made of a fiberglass outer structural shell with a tape wrapped ablative liner and cannot be reused.

The exit cone will be cut with a linear shaped charge prior to ignition of the drogue pilot chute mortar deployment. Since the rocket motor will be tumbling, this cone will be ejected into the free stream by centrifugal force dynamics. Because the drag-to-weight ratio of the exit cone is much larger than that of the primary body, this debris will be separated far enough to prevent collision.

The thermal environment inside the parachute compartment must be kept low (less than 165°F). The external aerodynamic heating is low ($\Delta T = 200^\circ\text{F}$) as is also the heat transfer from the nozzle. During rocket firing, the fiberglass exit cone must be held to a temperature less than 100°F to maintain structural integrity. The only heat source of concern is radiation from the exhaust plume. Some insulation and reflection material will have to be placed on the aft end of the recovery parachute compartment to protect against the heat load from the plume.

The aft skirt was analyzed with respect to the loads imposed by the suspension system. These loads will be transmitted through attachment points, located 180 deg apart on the aft skirt. Each of these points is designed to be capable of 600,000 lb in tension for pad holddown and is strong enough to withstand the parachute loads. The riser bridle will have to be carefully routed inside the parachute compartment to prevent tangling. These bridles will include one pilot drogue riser attached to the drogue package, one drogue riser attached to both holddown points, a pilot main riser attached to each main parachute cluster package, and a bridle for the main parachute system to be attached to the aft skirt. Each of these bridles will require a pyrotechnic cutter to release each parachute system when it has completed its functional sequence.

Goodyear conducted some tradeoff studies between the drogue size and weight vs the main parachute strength. The larger the drogue parachute, the more the body is slowed for main parachute deployment. The lower the velocity for main parachute deployment, the lower the opening loads and, hence, the lighter the weight of material which can be used.

In sizing chutes, Goodyear selected fairly large, very heavy duty drogue parachutes and a lighter main chute system.

State-of-the-art for design, development, and manufacture of ribbon type parachutes is considered to be up to 120 ft in diameter for deployment up to Mach 1.2. The weight of a parachute based on a per unit area/per unit load criteria, increases by the diameter to the 1.5 power. Thus, the larger the chute, the lower the weight efficiency.

Clustering of parachutes presents some deployment problems (tangling, partial inflation). The aerodynamic efficiency decreases as the number of parachutes in a cluster increases. Because of geometry reasons, subclusters in general must be groups of three, and for a 100 fps terminal velocity, the combinations considered for the main chutes were as follows.

1. Three 115 ft diameter chutes.
2. Six 81 ft diameter chutes.
3. Nine 66 ft diameter chutes.

Six 81 ft diameter parachutes were selected because this configuration appears to be best for minimum weight and minimum development cost.

The ribbon type design was selected for all parachutes because of the inherent capability of this type to accommodate high canopy loading. This type also exhibits a consistency of performance that indicates it is relatively insensitive to canopy loading over a broad range (3 to 30 psf).

Preliminary analyses indicate that the case can survive a 100 fps water impact and the parachute system has been designed for this value.

If the current design of the 156 in. segmented case cannot withstand this impact velocity, detail tradeoff studies between beefing up the primary structure, resizing the parachutes, or designing a retrorocket system will need to be conducted.

Should lower water entry velocities prove desirable, a previous study* has shown that a combined parachute and retrorocket system may provide the lighter, more desirable recovery system.

*French, K. E., "Parachute and Retro-Rocket Landing System for Vertical Descent," J. Spacecraft and Rockets, Vol. 2, N.J., September-October 1960, pp. 797-799.

For instance, the retrorocket weight required to slow the booster from 100 fps to zero velocity would require a 2,000 lb retrorocket system. If these rockets were fired when the booster was 100 ft above the water surface, they would have to operate for 2 sec and deliver an axial thrust of 235,000 lb. The 100 ft altitude signal for rocket motor ignition could be sensed by a radar proximity type fuse.

5.6 RECOVERY HYDRODYNAMICS

The primary requirement that the expended SRM must survive water impact with a minimum of damage establishes as the critical parameters: (1) primary orientation (nose down or nozzle down), (2) impact velocity, and (3) impact angle. Preliminary analyses were conducted to evaluate both nose first and nozzle first entry at 50, 100, and 150 fps impact velocity.

The axial accelerations imposed on the booster and the nose depth history for impact velocities of 50, 100, 150 fps are presented in Figures 5-4 and 5-5.* The body rebound velocities for the three impact velocities also are shown. At an impact velocity of 100 fps the body will enter the water to a depth of 66 ft. Preliminary analyses indicate that the hydrostatic pressure at this depth is not sufficient to cause buckling of the case forward dome or the cylindrical section immediately aft.

The anticipated sequence of nose first impact is as follows. At initial contact of the nose, the water will behave as a highly viscous fluid and a shock wave will be formed which travels in the fluid at approximately 5,000 fps. The structure at the tip of the nose cone will probably be slightly crushed and although the skin of the nose cone is supported by a heavy ring and stringer structure, some local skin buckling or rupture may occur. After the initial impact, the SRM will continue to travel downward in the fluid; the mass acting downward, drag and bouyant forces acting upward. As penetration continues to maximum depth, drag and momentum forces decay to zero and the bouyant force increases to a maximum causing the body to rebound upward toward the surface. The nose cone will exit from the surface to a height of 38 ft. A second impact of the nose cone with the water will occur, probably not symmetrically, and the SRM will fall over on a side in a slapdown mode. The slapdown loads could be as great as 10 g acting nearly normal to the SRM longitudinal axis with a maximum pressure load of about 30 psi imposed on the aft skirt. Flotation gear located near the SRM nose will inflate and cause the body to float, nozzle slightly down, and nose out. A sketch, Figure 5-6, illustrates this sequence of events.

*National Engineering Science Co, "Recovery of Booster at Sea," NASA X67-19630, April 1967

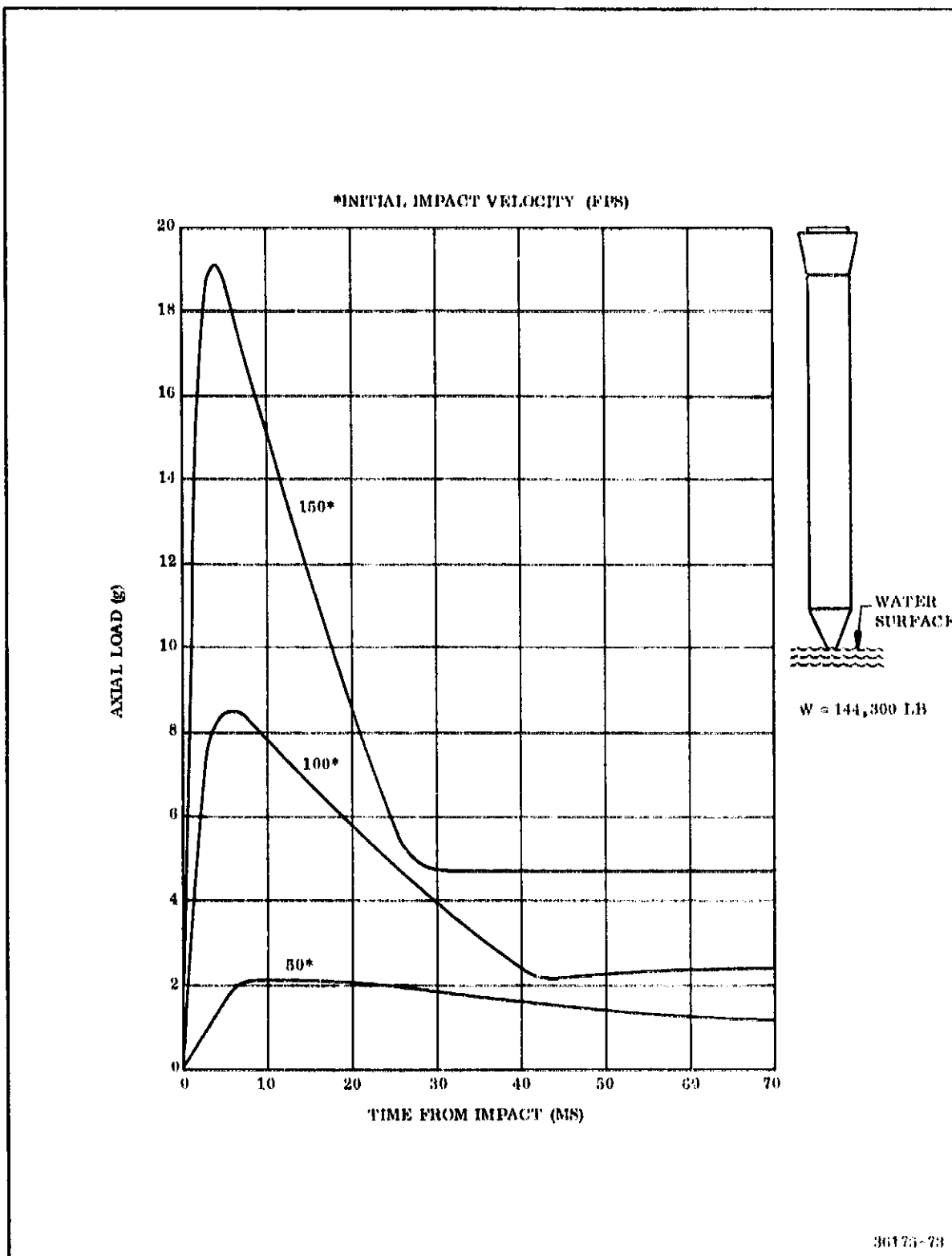


Figure 5-4. Vertical Water Impact Loads for Different Impact Velocities

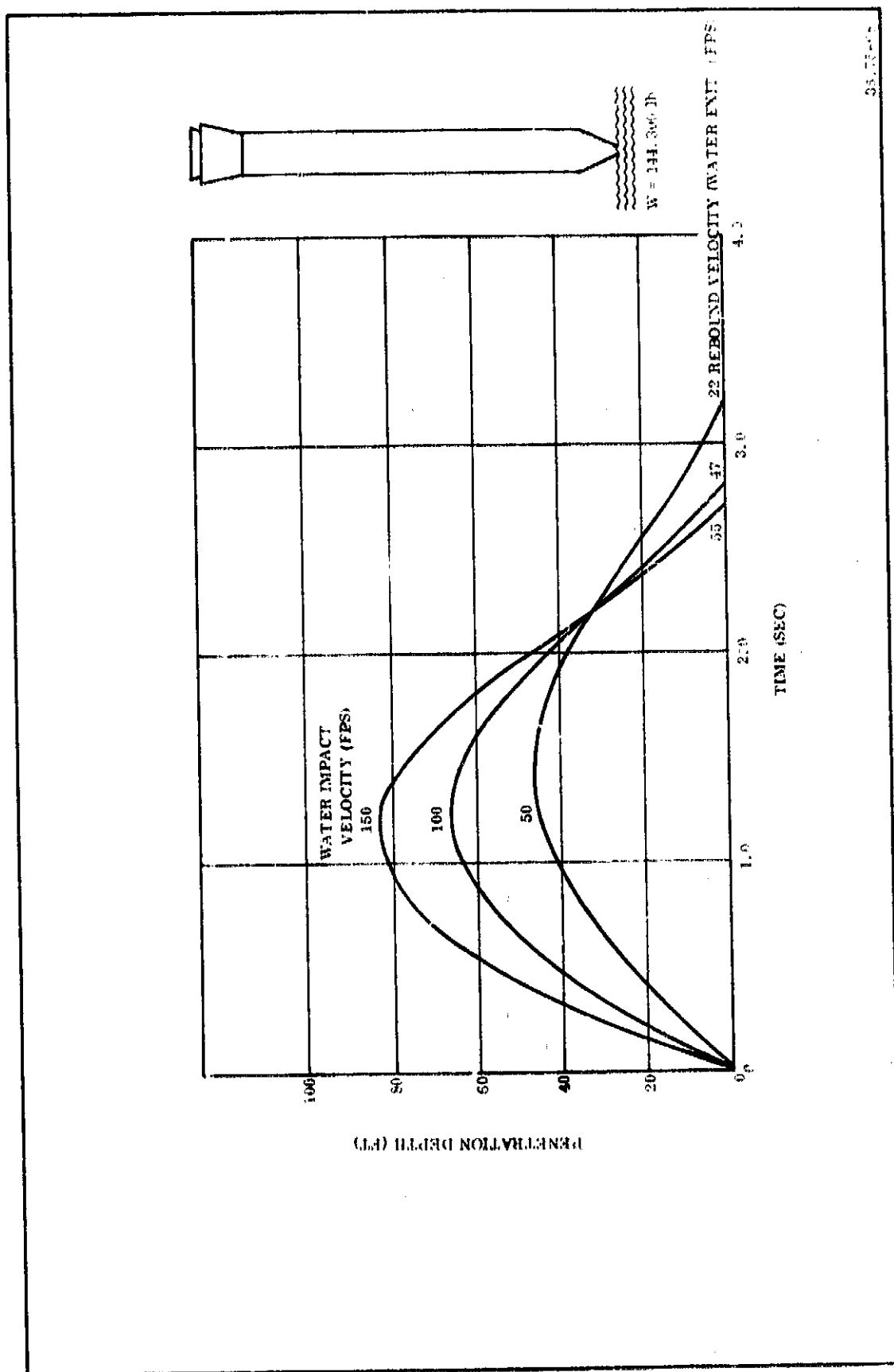


Figure 5-5. Vertical Water Penetration Depth History (Nose First Initial Water Entry)

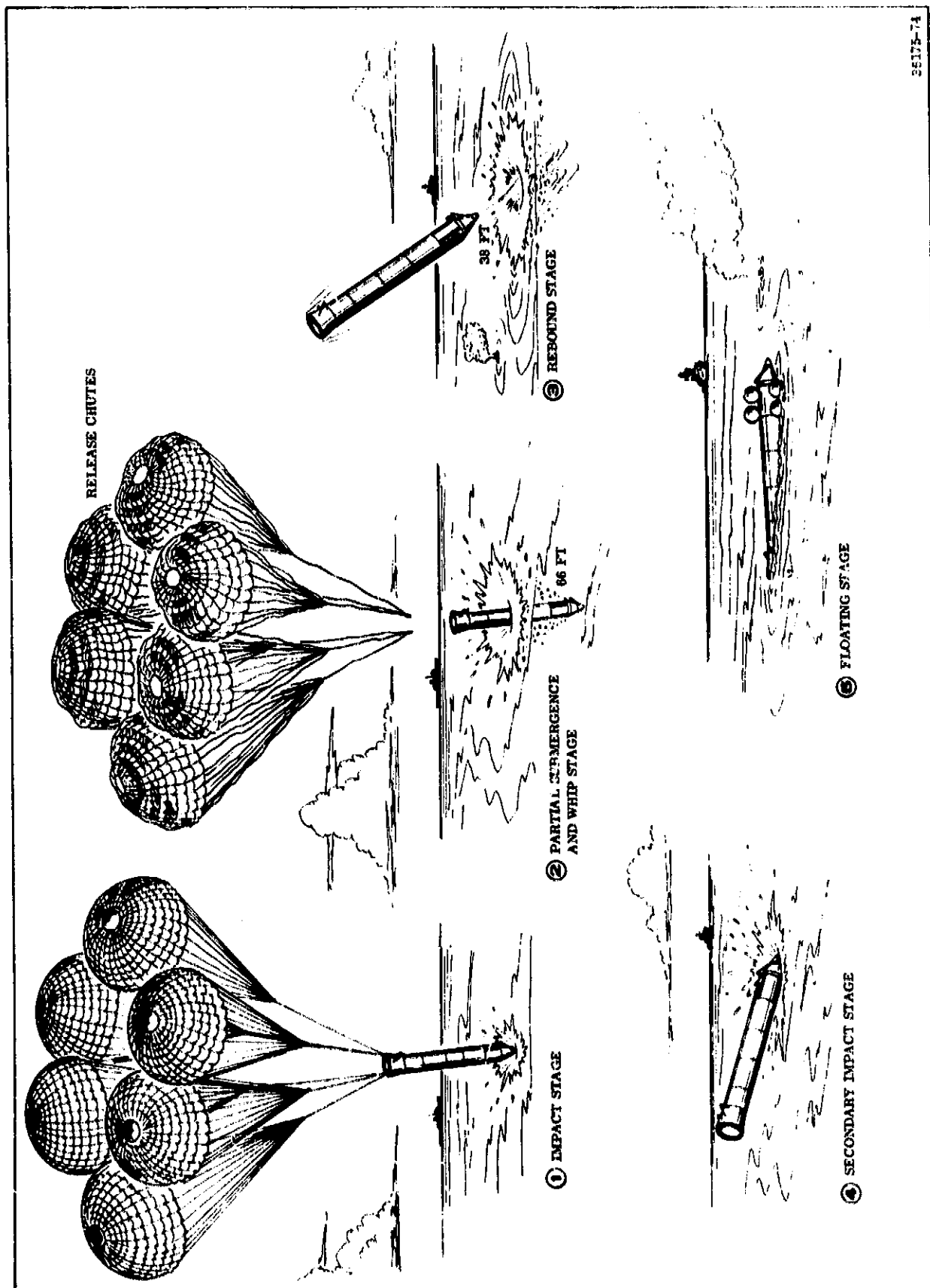


Figure 5-6. Water Entry Sequence

In nozzle first entry, the nozzle of the booster enters the water vertically, a wave is formed which detaches itself from the wall outside the aft skirt and piles up on the inside of the nozzle and the cavity between the nozzle and the skirt. Water will flow up the nozzle and also will flow into the cavity exterior to the nozzle. The flow up the nozzle will continue until the equilibrium is reached between the pressure of the compressed air inside the rocket chamber and the kinetic hydrostatic head.

Since the volume inside the cavity formed by the aft skirt, the nozzle, and the aft dome is small, high hydrostatic/pneumatic pressures will be felt on the inside of the skirt structure. Damage to the aft skirt and the hydraulic control system housed in this structure and aft dome may result.

The overall loads imposed on the primary structure during nozzle first entry should be about two-thirds of those imposed by a nose first impact. The hydrostatic loads due to depth penetration will be from the inside out (ie, internal pressure). The case is designed as pressure vessel and the structure will easily withstand the incident pressures.

These problems have led to the preliminary selection of the nose first entry.

5.7 CASE RECOVERY

The baseline recovery condition for the 156 in. parallel burn SRM has been defined as a vertical, nose down water entry at a velocity of 100 fps. With these initial conditions, it is calculated that the motor will penetrate to a maximum depth of 66 ft before all of the kinetic energy is expended.

Figure 5-7 shows a schematic view of the motor in the maximum penetration condition. The hydrostatic pressure head at various sections on the case and nose cone is shown as well as typical lengths of case sections.

This attitude of entry (vertical) is especially attractive from the standpoint of structural efficiency since the parachute deceleration loads can be fed into the case near the aft skirt holddown points. These load points are initially required to support the entire Space Shuttle assembly prior to launch and to hold down the assembly at full thrust after ignition and before release. Each point is capable of reacting an aft directed load of 600,000 lb for a total load capability of 1.2×10^6 lb for two points. The maximum snatch load of the drogue chute is calculated to total 600,000 lb while the maximum load in main chute system is predicted to be 300,000 lb. The loading inherent to this system of entry can, therefore, be easily accommodated with a minimum of additional structural weight. This compares with (1) an angular entry where a harness is necessary to control the attitude and transmit the 600,000 lb drogue chute load into the case or, (2) the nozzle first entry where the structure in the nose cone must be utilized. This nose cone structure is heavy, but initial design requirements (motor support and boost) are primarily compression loads.

The first real structural encounter in the recovery sequence occurs when the vehicle makes its initial contact with the water. At this time, a relatively high magnitude acoustic wave is propagated due to the slight water compressibility. The shock pressure behind this wave acts for a very brief duration on the initial area of contact. The predicted duration of this load is shown in Figure 5-4. Since these pressures act over a relatively short duration of time, they generally cause no structural problem but produce a "ringing effect." However, a thorough investigation into the dynamics of the hydroimpact problem must be conducted as part of the total recovery study to determine the exact magnitude and duration of these entry loads. Much can be done either to accommodate or help attenuate these loads should they prove to be a problem. Possible solutions include a crushable (energy absorbing) nose cone tip, an optimum hydrodynamic shape, or merely letting the nose cone skin crush as an energy absorbing mechanism.

The second structural effect of the water entry is a sharp deceleration of the vehicle due to the acoustic pressure effect. Figure 5-4 shows that the maximum deceleration for 100 fps reentry velocity is approximately 8.5 g. The axial load resulting from this magnitude of deceleration is of no consequence at all to the case which can withstand approximately 100 g (empty) before axial buckling becomes a factor.

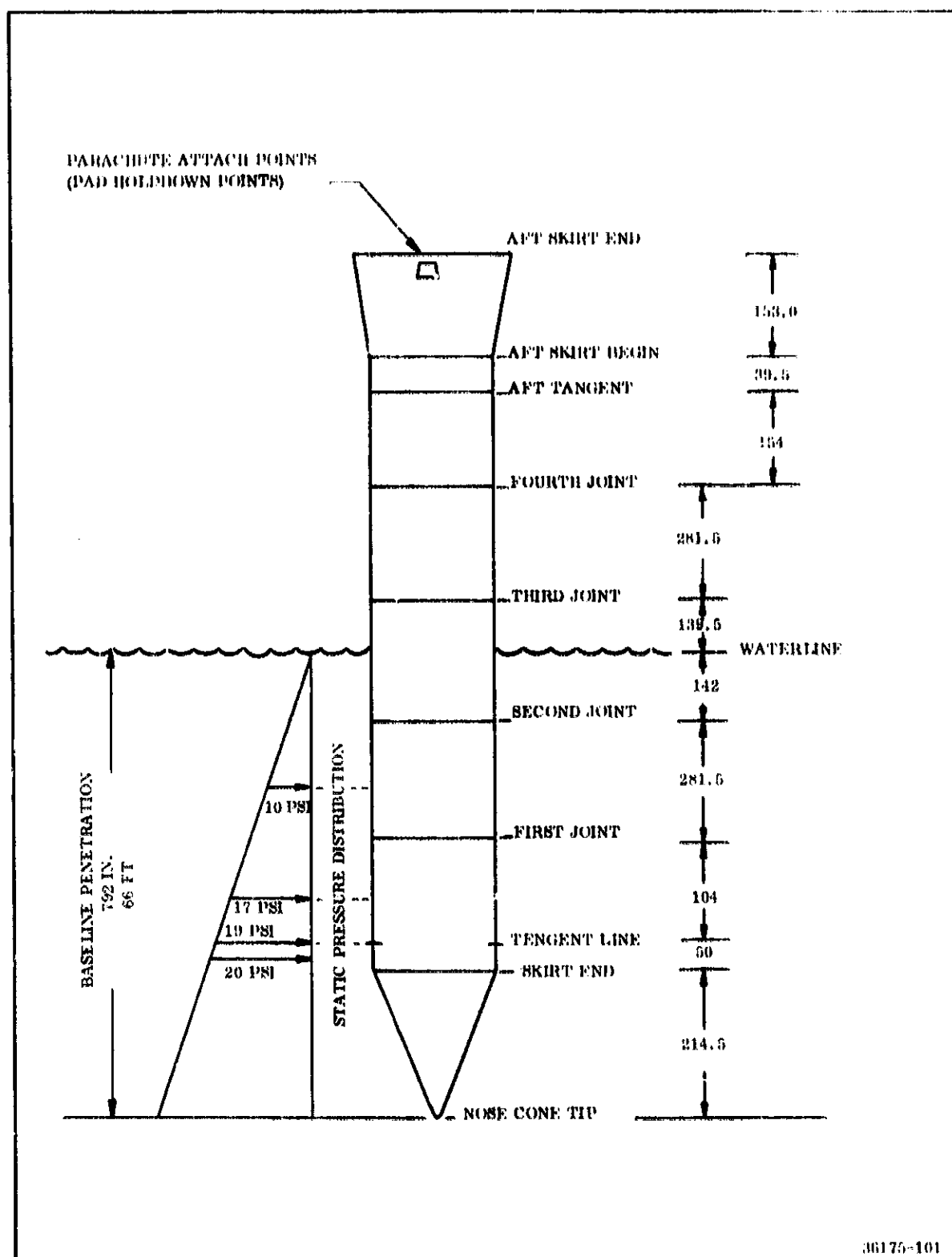


Figure 5-7. Case Recovery, Maximum Penetration Condition

At the point of maximum penetration (Figure 5-7), one of the most severe structural load conditions occurs, that of hydrostatic head pressure of the sea water. In this condition, the major consideration is the hydrostatic buckling of the cylindrical section of the case. Preliminary calculations based on the assumptions of a short cylinder over one maximum segment length (281.5 in.) indicated that the critical hydrostatic buckling was 48 psig for a D6AC case. Subsequent calculations indicated, however, that the effective moment of inertia of the segment joint sections was not high enough to insure short cylinder buckling response within an individual segment. The next approach, which was taken to establish a lower boundary for buckling, was to assume that the entire motor case was only held circular at the end tangent points and to completely ignore the contribution of the clevis joints. These assumptions produced a predicted buckling allowable of 8.75 psig. It is more realistic to assume that the section of the case above the waterline forms a ring stiff enough to hold the assembly circular at the waterline but not otherwise constrain it. Previous extensive experience in the SRM case industry has shown that a hemispherical dome tangent provides an extremely stiff boundary for buckling on the forward part of the case.

Under these assumptions, there are 528 in. of case cylinder submerged and subjected to hydrostatic pressure. Using this value for cylinder length, the lateral buckling pressure allowable becomes 19.5 psig. Figure 5-7 shows that the maximum hydrostatic pressure on the cylinder at baseline submergence is 19 psi. The D6AC case may be marginal and more refined analyses are required to assure that nose down reentry is acceptable.

One other possibility of an overpressure condition in excess of hydrostatic head could exist if significant cavitation occurs during entry and then collapses against the case. This problem has not yet been addressed analytically due to the complexities involved but must be fully evaluated as part of a future recovery study.

The cavitation effect can be minimized by the proper selection of the nose cone shape, and the buckling capability of the forward sections of the case could, if necessary, be substantially increased by the addition of an internal stiffening ring or an external or internal honeycomb jacket.

The preceding case capability calculations do not include any effects of asymmetrical loading but are presented only to demonstrate the basic feasibility of the nose first vertical entry approach to recovery.

After reaching maximum penetration depth, the vehicle will be expelled from the water by buoyancy forces to a maximum height of 38 ft. At this point, the attitude can no longer be controlled and the case will randomly tumble back to the surface of the ocean.

One of the more severe reentry modes would be a single point entry as shown in Figure 5-8. In this mode, the case is capable of accepting in excess of 30 g

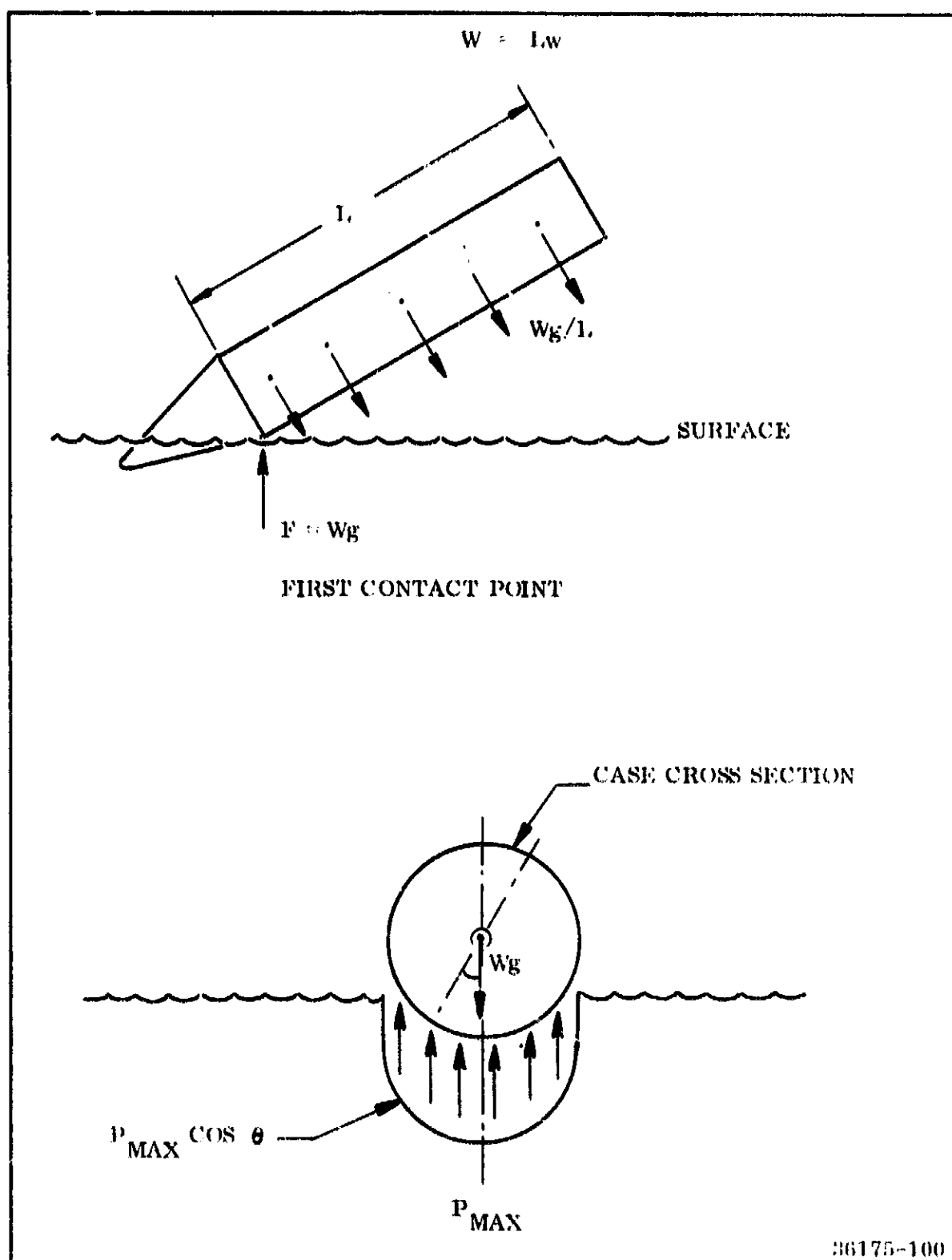


Figure 5-8. Point Re-entry Mode, Second Cycle Re-entry After Vertical Entry

without bending buckling. This seems highly unlikely since the axial g loading due to initial impact was only 8.5 g. It is also highly unlikely that the case will have time to assume a near horizontal attitude, as shown in Figure 5-7, which should be more severe than a more vertical reentry. It would seem that the initial impact on rebound would be less severe than an initial entry since the velocity (from a 38 ft fall) would be only 50 fps. The rebound impact at nonvertical attitude causes the body to whip. The whipping action causes the body to slapdown to a horizontal attitude near the water surface.

An additional potential problem area is the asymmetric saddle pressure that the case will experience during final horizontal slapdown. Figure 5-7 shows a typical distribution. It is not anticipated that this effect will present a critical problem, but it must be investigated thoroughly in the recovery study phase.

The salt water environment should produce no deleterious effects on a D6AC metal case if recovery and subsequent cleaning are rapid.

5.8 REFURBISHMENT

Following successful recovery of the spent SRM stage, refurbishment operations would be required to prepare recovered components for recycle and reuse. The following components would be refurbished for subsequent recycling in the program: (1) case, (2) nozzle structure, (3) stage attach structure, (4) HPU and actuation system, and (5) the recovery system.

Numerous assumptions were made in conducting the component recovery and refurbishment studies. A 90 percent hardware recovery rate (10 percent loss rate) was assumed and it was assumed that each component would be discarded after it had been used 10 times. Case and nozzle hardware are to be shipped from KSC to Thiokol/Wasatch Division for refurbishment and subsequent recycle. Refurbishment of stage attach structure, HPU's and actuation systems, and the recovery system will be accomplished at KSC. The cost data presented in Volume IV reflect these assumptions. Required refurbishment operations are described briefly in the following paragraphs.

5.8.1 Motor Case

The D6AC case will be recovered, disassembled, and flushed with treated water. After a thorough drying operation, the case can be inspected for visual damage such as scrapes, gouges, and cuts that might have been incurred during the recovery process. If any of the damage mentioned is observed, repair will have to be evaluated on an individual basis. If the case passes visual inspection, it will be treated with a suitable rust preventative and put into the normal processing line for hydrotest and reloading.

The 10-reuse requirement with its inherent 20 pressure cycles should not in itself prove to be limiting since this represents a very low number from a cyclic fatigue standpoint. The limiting factor will almost certainly be the accumulative damage incurred during successive recoveries.

Case reclamation does not present a major problem with respect to reinstallation of an acceptable insulator. Thiokol has demonstrated on the Stage I Minuteman and previous 156 in. motor firings the capability of reclaiming steel cases from static motor firings.

The reclamation procedure proposed for this program is to remove the total insulator from the fired case segment by applying localized heat to relieve the case insulation bond. The case would be subjected to a complete insulator fabrication process, the same as a new motor.

To further facilitate the reuse of the motor case, the nozzle joint, nozzle, and igniter will be installed and sealed with a noncuring compound to facilitate easy

removal after the motor has been fired. The selected material is number 3992 vacuum bag compound manufactured by the W. P. Fuller Company and this material has demonstrated excellent performance as a joint sealer.

5.8.2 Nozzle

Previous experience has shown in many instances that the metallic structures from fired nozzles can be salvaged, refurbished, and reused in building new nozzles. Resulting cost reductions from 10 to 20 percent are possible depending on the complexities of the structures.

Upon receipt of the recovered nozzles by Thiokol, the ablative and insulative plastics will be removed by heating in an oven to break down the bond line. The plastic components are not reusable and will be discarded. The metal structures will be cleaned, inspected, rust inhibitor applied, and shipped to the nozzle fabricator. On arrival, they will be thoroughly cleaned and inspected in detail to verify that all design requirements can be met and that they are acceptable for reuse. The metal structures then will be incorporated into new nozzle assemblies.

The flexible bearing assemblies from movable nozzles also can be recovered. The elastomeric shims will be reclaimed and the end rings and metallic shims salvaged and refurbished for reuse. Such salvage and reuse operations have been successfully conducted by Thiokol in current flexible bearing nozzle programs.

It has been postulated that the entire bearing assembly may be reusable without removing and replacing the elastomeric shims which could effect even greater savings in nozzle costs. This would entail complete retesting of each recovered bearing assembly and verification of integrity by successful static test firing. This has not been done previously but would be evaluated during the development phases of the program.

5.8.3 Stage Structure

The SRM stage structure (forward and aft attachment structure, nose cone, and aft skirt) design will include the requirements (loads and environment) of staging impact and recovery. The 10 cycle reuse criteria will be applied to design and testing.

Selection of materials and fasteners will be highly levered toward a minimum sensitivity to corrosion effects. The design and materials will be amenable to the repair of unplanned damages and nicks and gouges. In general, the pertinent aspects of marine design criteria will be applied.

The total recovery sequence will be evaluated relative to an SRM stage designed for launch and flight conditions. That is, by controlling the attitude of

impact, recovery might not affect the SRM design; however, a detailed cost trade study is indicated.

The stage structure will be processed through the same recovery and cleansing cycle as the case; flush with treated water, dry, inspect, repair, and protect. The components then would be stored at or near the launch site for scheduled reuse.

5.8.4 HPU and Actuation System

Refurbishment of the entire nozzle actuation system and controls is recommended. Similar equipment currently used on large solid rockets (Poseidon, Spartan, Nike-Zeus, etc) have been reused many times.

The HPU and controls selected for the 156 in. SRM application has a life expectancy of 61 hot starts without major refurbishment, other control components such as reservoirs, filters, accumulators, servoactuators, control boxes, etc, are designed to equal the HPU operation life. Therefore, all the associated control equipment will have a comparable life expectancy. For estimating purposes, recycling of the HPU and controls hardware appears realistic.

External environmental protection of the component housings will be accomplished with epoxy coating. Other components will have a bonded rubber coating over high corrosion surfaces. Since all the hydraulic system and all the turbine fuel system is sealed, no salt water can enter either of the internal systems. Therefore, the only major problem is the external component protection.

The major concern is the electrical equipment and their connectors. Selecting a waterproof mechanical joint for the electrical application will be the most difficult. Prior to the selection of the connector configuration, a verification type test program will be established to help isolate potential problem areas. For cost estimating purposes, Thiokol expects to completely replace all electrical harnesses and associated connectors.

Refurbishment of the HPU and controls will be accomplished at the launch site. Refurbishment will in many instances include complete teardown, examination, reassembly and rerun of the acceptance testing.

5.8.5 Recovery System

The assumption is made that the main chutes, both drogues, the mortar, and the beacon will be refurbished. The pilot chutes, deployment bags, main and drogue chute risers, and flotation gear will be expendable.

The recycling plan includes off-loading the recovered parachutes on the dock of the refurbishment facility through the parachute packing cycle and returning to inventory awaiting delivery to the mission vehicle as follows.

1. Off-load the recovered parachute on the dock.
2. Separate chutes, remove flotation gear, and untangle and defoul suspension line.
3. Wash chutes.
4. Dry chutes.
5. Inspect chutes for damage.
6. Repair chute damage.
7. Rig and install flotation gear.
8. Install reefing system.
9. Pack chutes.
10. Move parachute pack assembly to inventory stores.

The mortars and the beacons will be sent back to their respective vendors for refurbishment.

6.0 ENVIRONMENTAL EFFECTS

Thiokol Chemical Corporation has made an extensive study of the environmental effects of Space Shuttle configurations consisting of large solid propellant boosters coupled with a liquid fueled orbiter. Thiokol funded Geophysical Corporation of America (GCA), Technology Division, Salt Lake City, Utah, to perform subcontract work defining the effect of gases emitted from the shuttle motors. GCA used extensive mathematical modeling developed for NASA Marshall Space Flight Center. Thiokol also funded Bolt Beranek and Newman Inc., Bedford, Massachusetts, to perform acoustic analysis of the near and farfield noise generated by the combined shuttle motors.

The results of these extensive studies show that no environmental problems should occur.

6.1 EXHAUST GAS TOXICITY ANALYSIS

The exhaust gas from the SRM's is made up of the following components:

<u>Percent by Weight</u>	
CO	24
CO ₂	3.7
HCl	21.5
H ₂ O	9.5
N ₂	8.8
H ₂	2.1
Al ₂ O ₃	30.2
Misc	0.2

The potential environmental hazards posed by these products fall into three categories:

1. Ground level concentrations or dosages of toxic products exceeding toxicity levels in uncontrolled areas.
2. Possible damage to vegetation or other receptors due to surface deposition of exhaust product.

3. Possible long term buildup of foreign species in the stratosphere.

Thiokol subcontracted the work of analyzing these possibilities to GCA. Computer programs developed for NASA and the U.S. Air Force were used by GCA to quantitatively assess the first two potential problems. The toxicity criteria assumed were derived from previous work done for NASA by GCA. Figures 6-1 thru 6-6 show for normal launch and for pad abort, in which both SRM's burn out on the launch pad, that peak concentrations are well below allowable limits.

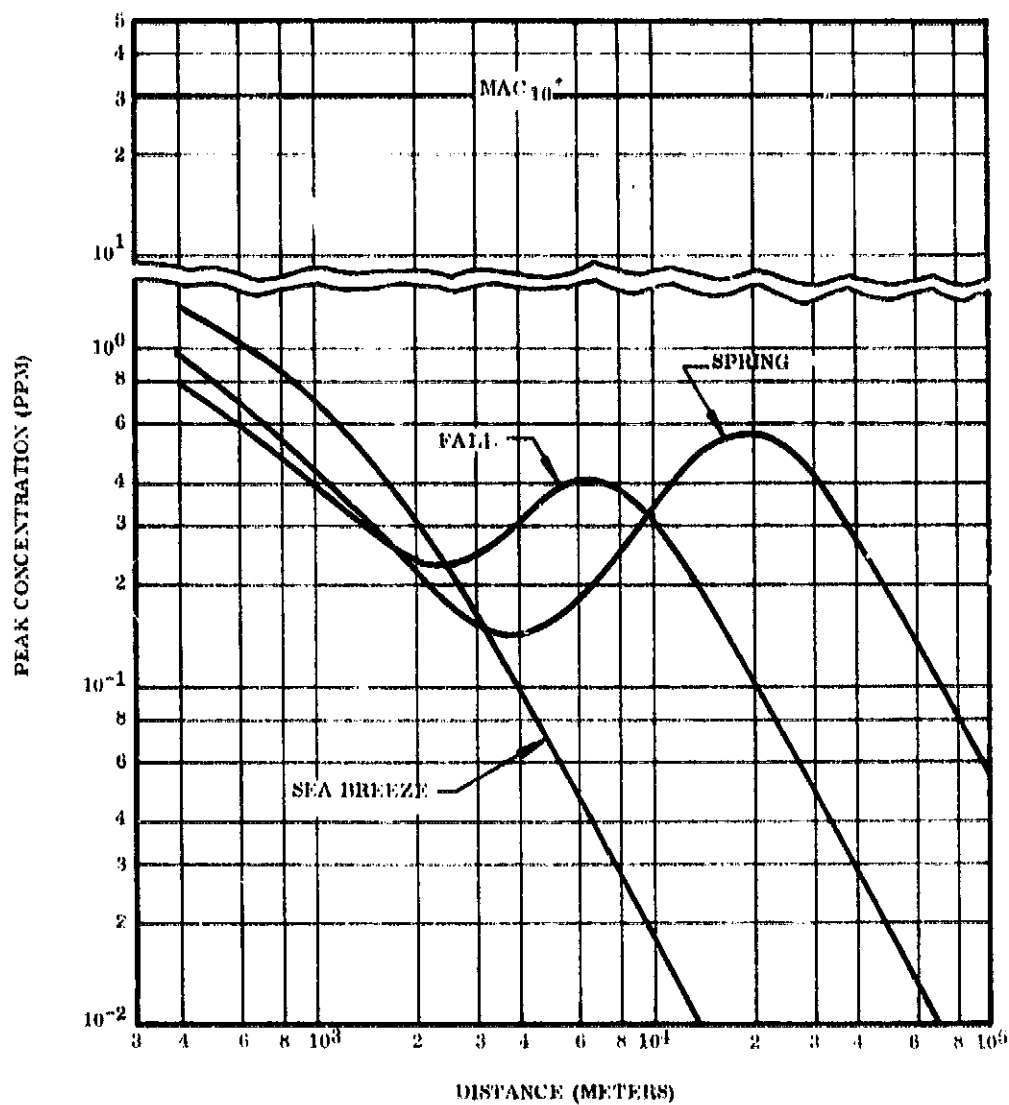
For the stratosphere problem, it was assumed that no danger exists if the products diffuse to ambient values. If a product is not a normal constituent of the stratosphere, the ambient value used was for that of trace elements such as xenon.

Three launch conditions have been considered. In the normal launch, both SRM's and the LOX engine are considered to be fired simultaneously. In the pad abort, two SRM's burn at the normal rate while the boosters are held down on the launch pad. The destruct case considers that both SRM's and the LOX engine release all their products instantaneously to the atmosphere at an altitude of 2 km.

Three meteorological regimes, spring, fall and sea breeze, were considered. They are characteristic of those conditions which exist at Kennedy Space Center (KSC). All three regimes were assumed to include a thermal inversion. The most severe inversion was for the sea-breeze regime and consisted of a 3°C temperature rise between 0.3 and 1.0 km altitude.

The results of GCA's computation for the tropospheric problems show that:

1. For the three meteorological regimes considered, the ground level concentrations of HCl, Al_2O_3 and CO are all below the maximum allowable 10 min concentration levels for both a normal launch and an on-pad abort in which both of the solid propellant motors complete propellant burn with the vehicle in a holddown status.
2. For a low level vehicle destruct event at an altitude of 2 km, calculations show that for a stabilized cloud of exhaust products at an altitude of about 4 km having an approximate diameter of 2 km, average concentrations of CO (50 ppm) and Al_2O_3 (35 mg/m³) within the stabilized cloud would be well below the ground level toxicity criteria and the corresponding HCl concentration (30 ppm) would be equal to the ground level limit.
3. The formation of an acid mist is possible only in situations where the ambient humidity approximates 100 percent; the



*MAXIMUM ALLOWABLE CONCENTRATION FOR
10 MINUTE EXPOSURE

36175-24

Figure 6-1. Peak Centerline Concentration of HCl at Ground Surface Downwind from a Normal Launch

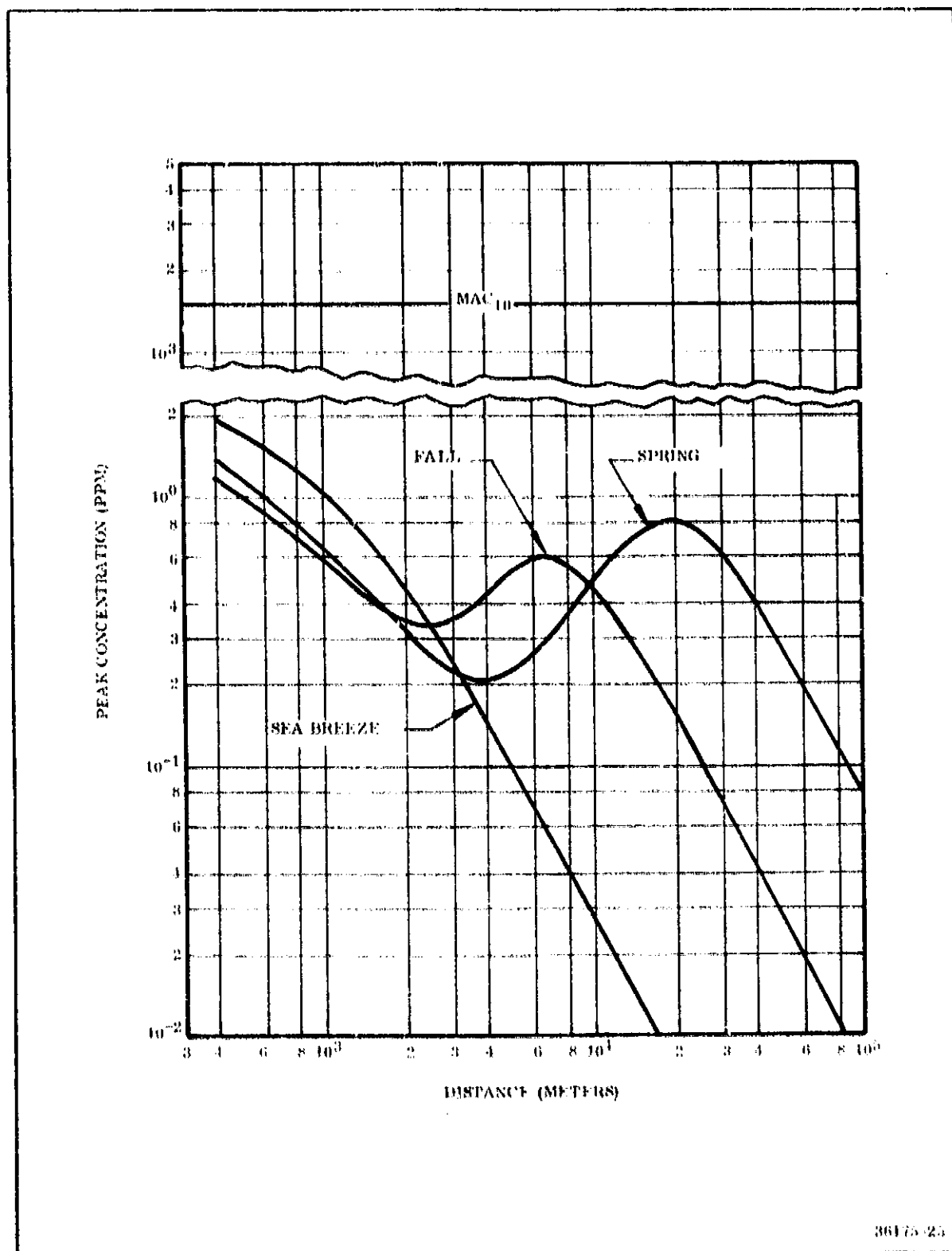


Figure 6-2. Peak Centerline Concentration of CO at Ground Surface Downwind from a Normal Launch

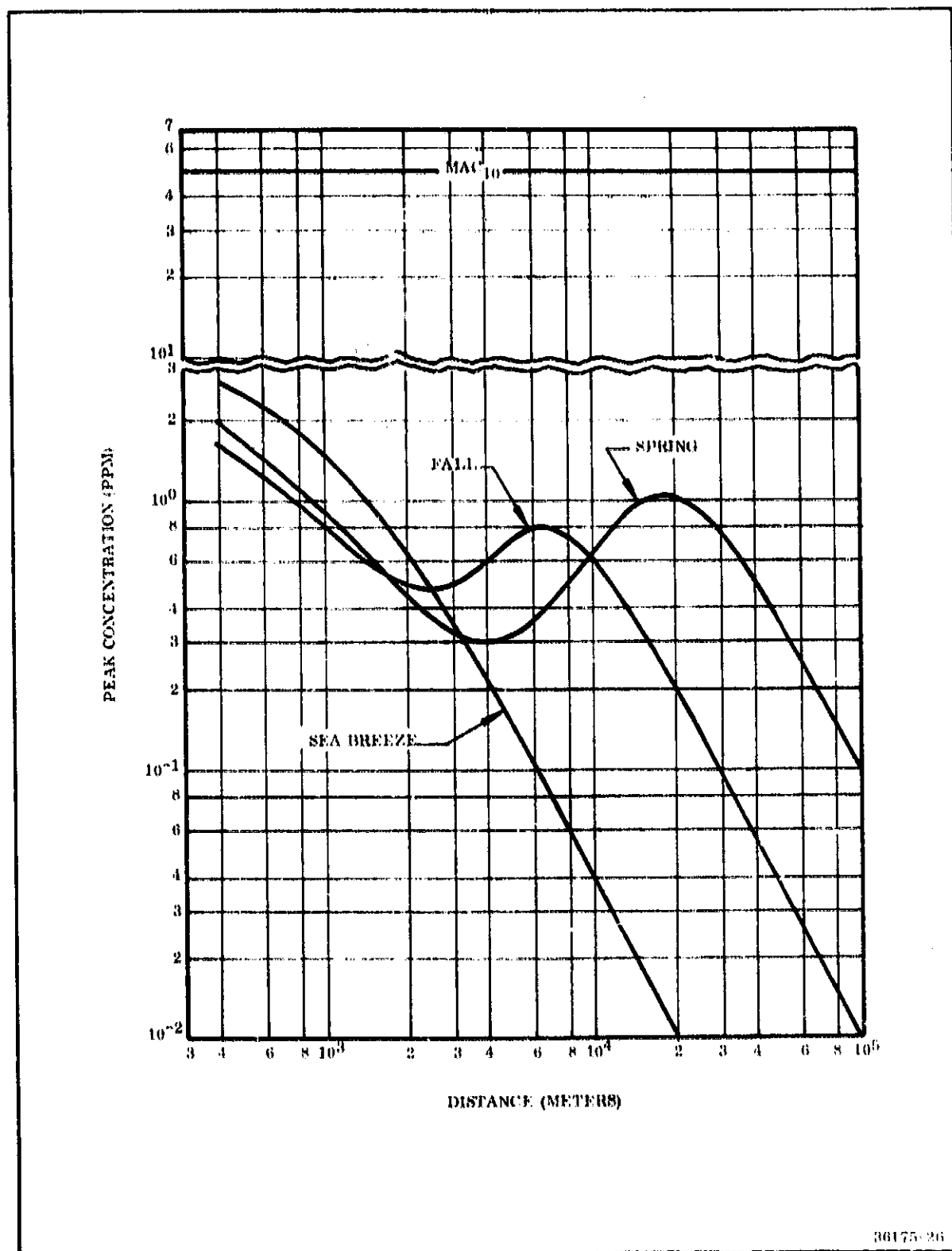


Figure 6-3. Peak Centerline Concentration of Al_2O_3 at Ground Surface Downwind from a Normal Launch

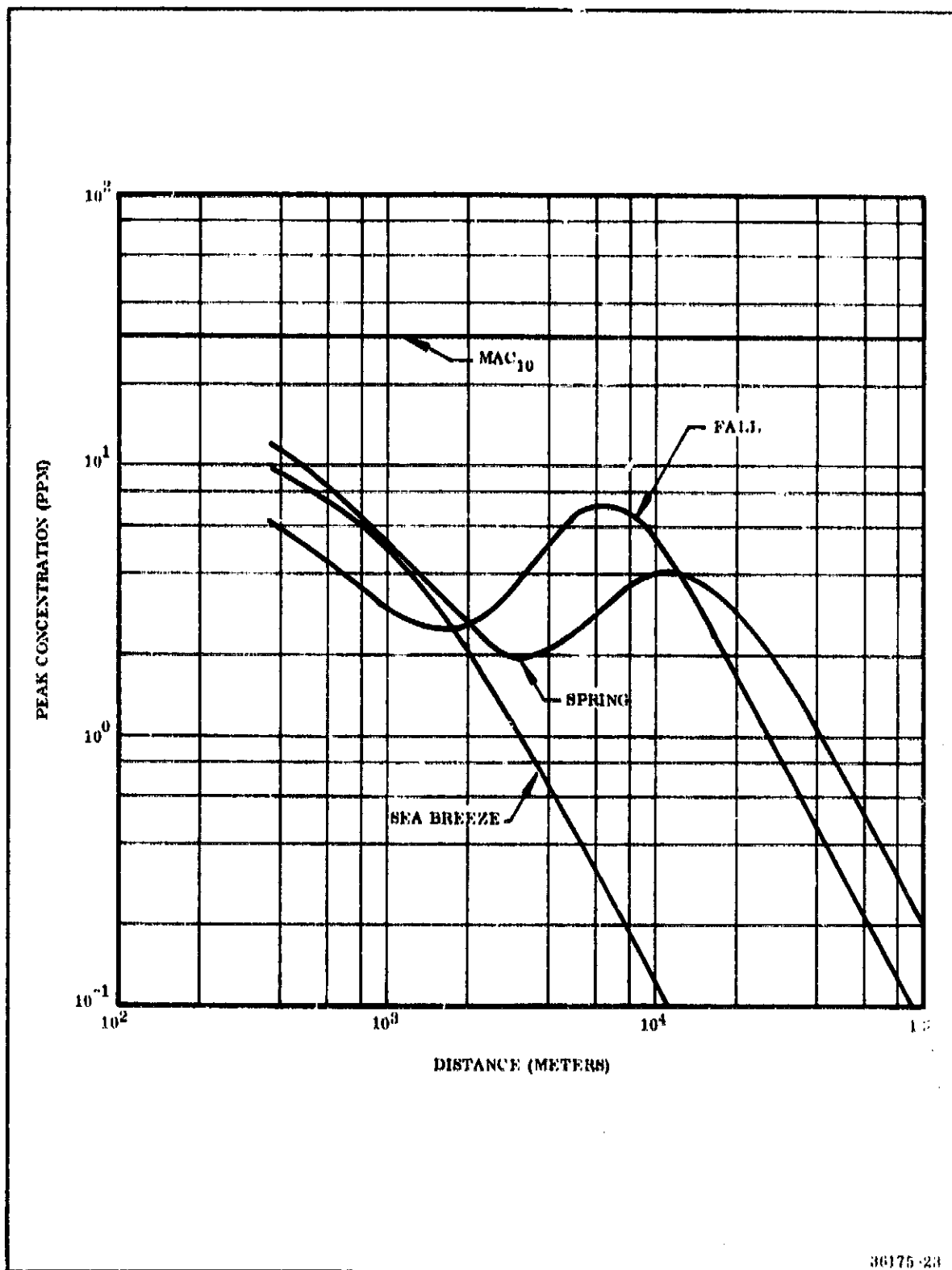


Figure 6-4. Peak Centerline Concentration of HCl at Ground Surface Downwind from a Pad Abort (Both SRM's Ignited)

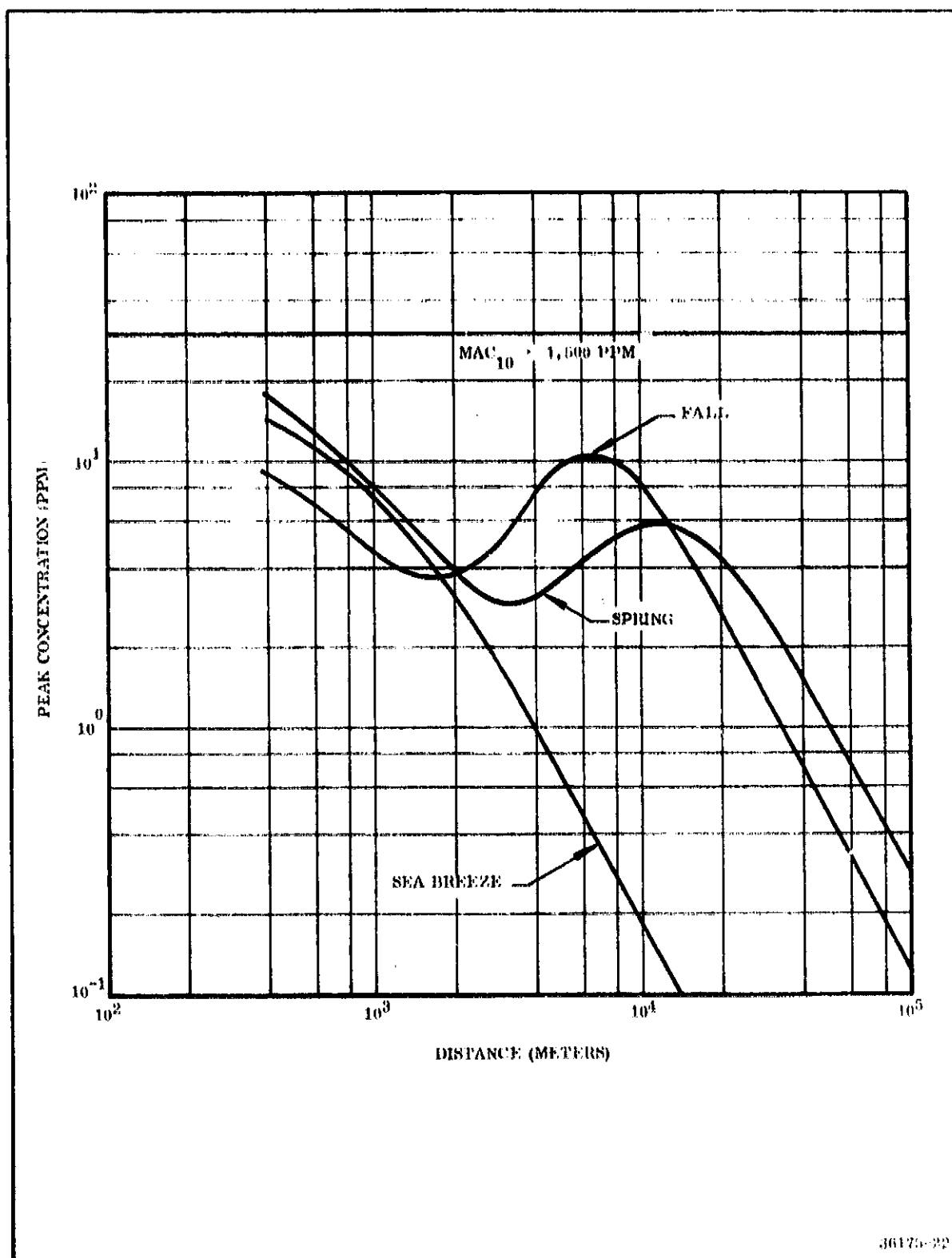


Figure 6-5. Peak Centerline Concentration of CO at Ground Surface Downwind from a Pad Abort (Both SRM's Ignited)

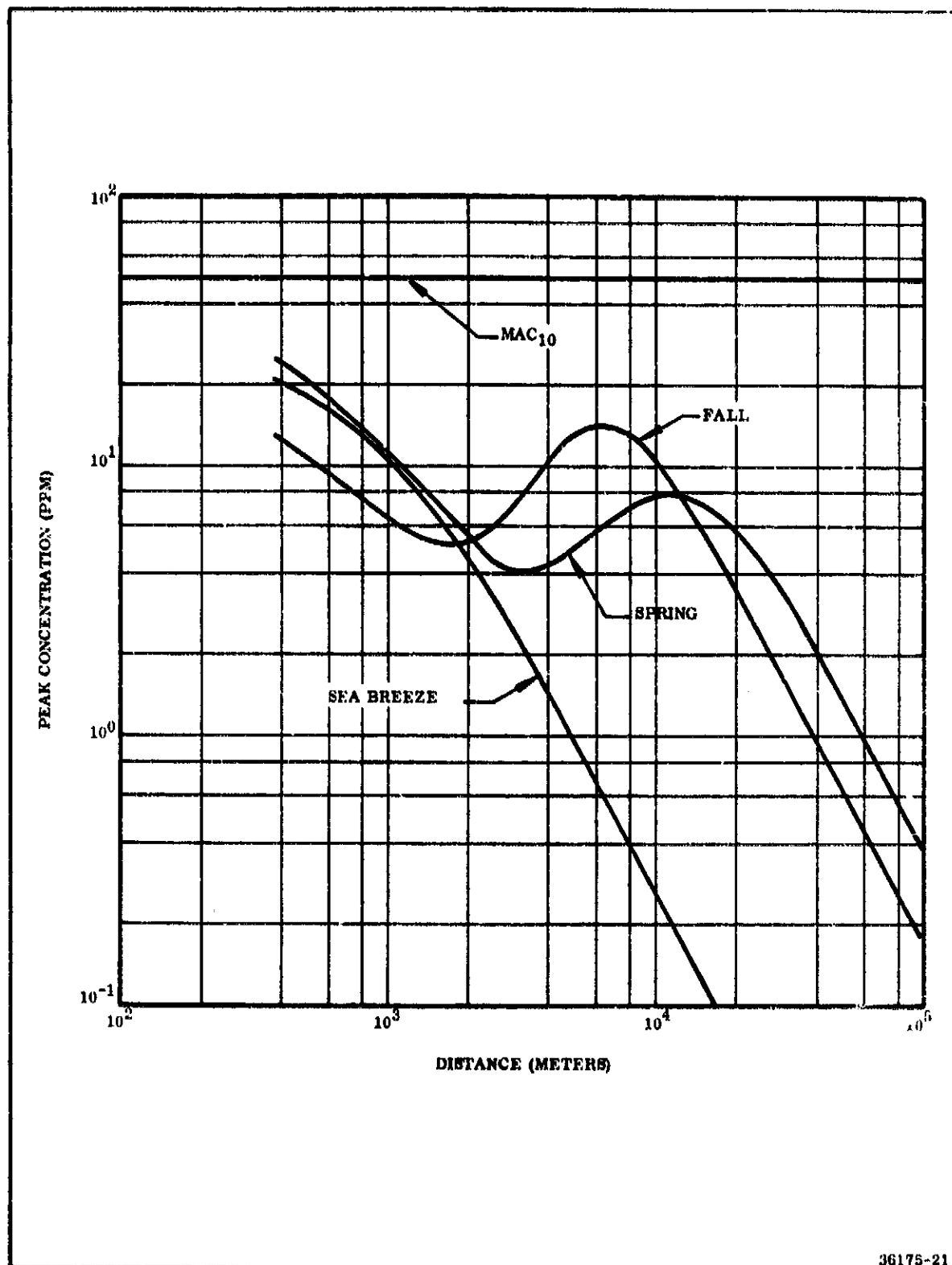


Figure 6-6. Peak Centerline Concentration of Al_2O_3 at Ground Surface Downwind from a Pad Abort (Both SRM's Ignited)

production of an acidic drizzle or rain that will reach the underlying surface in significant amounts appears to be extremely remote. The formation of small water drops within the exhaust cloud with an acid content of 1 to 5 percent by weight is possible if a sufficient ambient supply of water is available.

4. Calculations of the maximum removal of HCl from the exhaust cloud by falling precipitation show that the maximum surface deposition of HCl ranges from about 0.26 to 4.2 gm/sq m, depending on the time after launch at which the precipitation begins. Although we are not aware of detailed studies of the effects of HCl on vegetation and other receptors, concentrations in this range appear to be potentially capable of producing harmful effects.

There is evidence that the methods used to evaluate toxicity problems described above are conservative. Data taken during Titan IIC firings have shown concentrations of HCl to be only slightly greater than 3 ppm at 50 ft, while the critical predictions were 30 ppm at 500 ft.

The stratospheric computations showed that concentrations of CO₂ and N₂ would fall to ambient levels within a few minutes after passage of the shuttle, and H₂O levels would return to ambient values within a few hours. An extremely conservative approach for determination of HCl, Al₂O₃ and CO in the stratosphere indicated that only trace levels were left after a couple of days.

It is concluded, therefore, that no stratospheric buildup will occur from launch rates as great as 60 missions per year.

In summary, it is concluded that no exhaust gas toxicity problem exists for normal or abnormal launch in normal weather conditions. It appears that the only problem that could occur would result from launches during rainstorms or if the exhaust gas cloud passes through a rainstorm within 100 km of the launch site. Even this hazard is minimal if the path for surface deposition is over water. It is expected that in nearly all cases the ground cloud would travel away from land. Details of the GCA study are presented in Appendix F.

6.2 ACOUSTICS

6.2.1 Farfield Noise Analysis

Noise is created by the shear forces between the exhaust plume and ambient air. Empirically, it has been found that for large rocket motors, a maximum of

six-tenths of 1 percent of the mechanical power is dissipated as sound. The mechanical power is defined as the thrust times the exit gas velocity. To get acoustic power, one simply multiplies mechanical power by acoustic efficiency (0.6 percent in our case). The overall sound power level (PWL) can be calculated from:

$$PWL = 20 \log_{10} \frac{(\text{acoustic power})}{10^{-12} \text{ watts}}$$

The overall sound pressure level (SPL) is further calculated from:

$$SPL = PWL - 10 \log_{10} A + 10.5$$

where: A = the area (in. sq ft) through which the acoustic energy passes. (On pad, A is that of a hemisphere. In flight, A is that of a sphere with a segment cut off by intersection with the ground.)

PWL and SPL are dimensionless and are given the arbitrary unit of decibels. The foregoing analysis is a simple approach to the farfield acoustics. No air or ground attenuation is accounted for - nor is directivity.

The following figures (6-7 thru 6-10) present the results of work performed by Bolt, Beranek, and Newman Inc., under subcontract to Thiokol. This work includes such effects as attenuation and directivity. Results for both near and farfield are included.

The noise from the Space Shuttle will be no worse than from previous Saturn V launches. Safety precautions should be similar to those for the Saturn firings.

6.2.2 Nearfield Noise

Prediction of nearfield noise is explained in Cradall's text "Random Vibrations."

Under subcontract to Thiokol, Bolt Beranek and Newman Inc. have calculated the acoustic environment on crew and cargo compartments. Thiokol completed the analysis by calculating the acoustic environment on the aft end of the orbiter.

No critical problem should be encountered. Structures can be adequately designed to withstand these acoustic loads.

The final report received from Bolt Beranek and Newman Inc. is contained in Appendix F and presents details of their analyses which have been summarized in the preceding paragraphs.

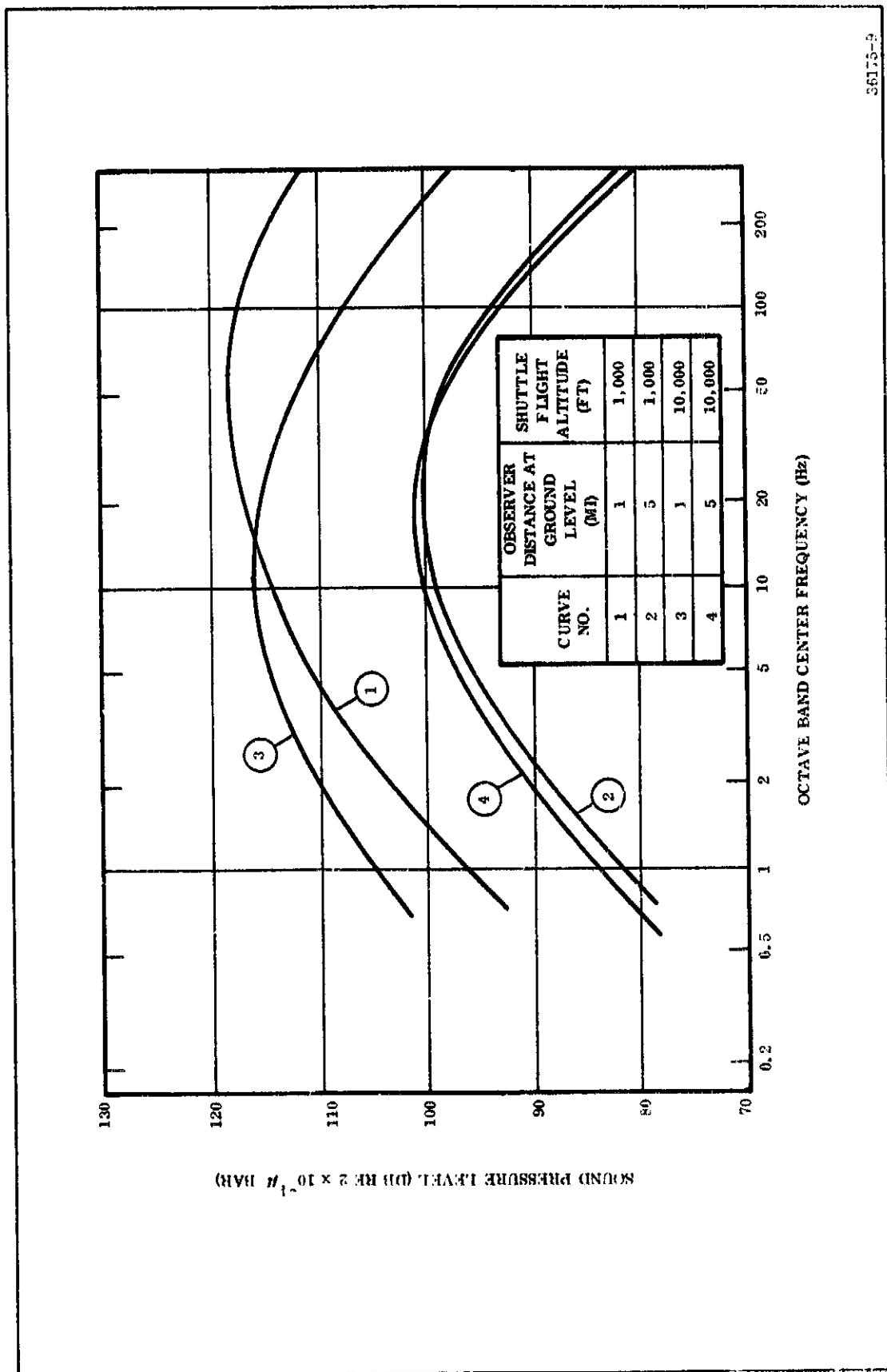


Figure 6-7. Octave Band Sound Pressure Level Spectra, Parallel Burn

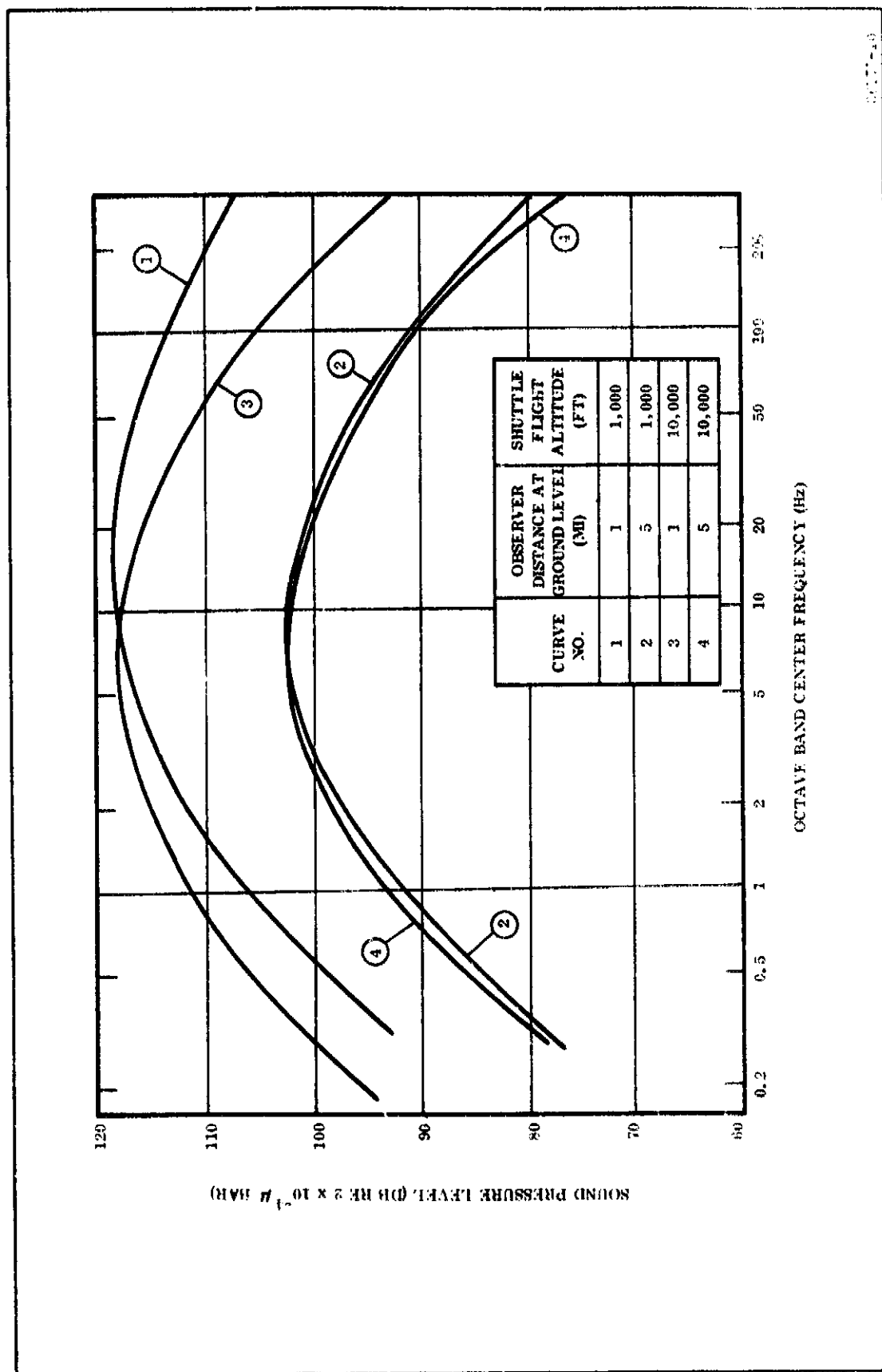


Figure 6-8. Octave Band Sound Pressure Level Spectra, Series Burn

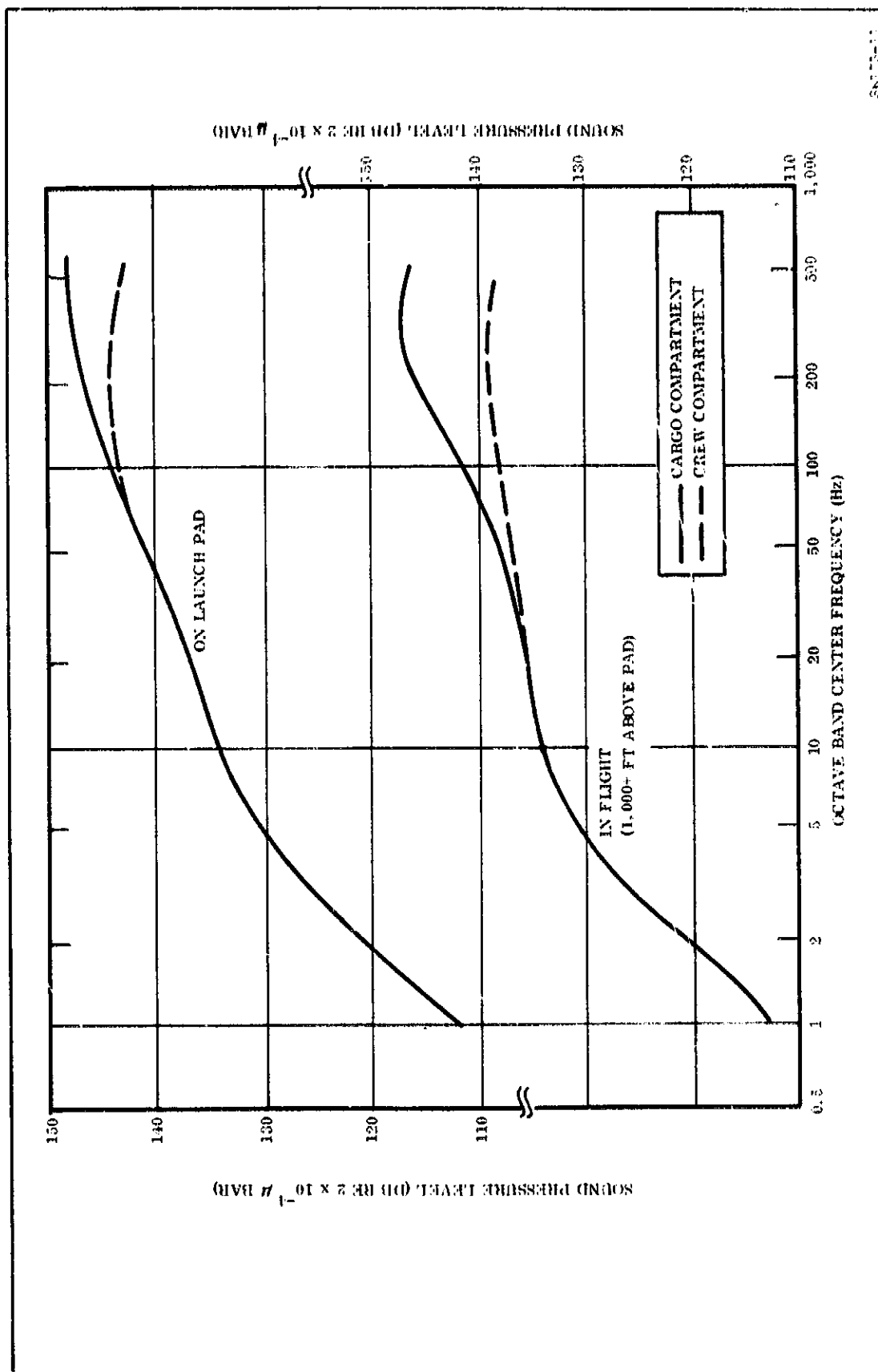


Figure 6-9. External Acoustic Environment, Parallel Burn

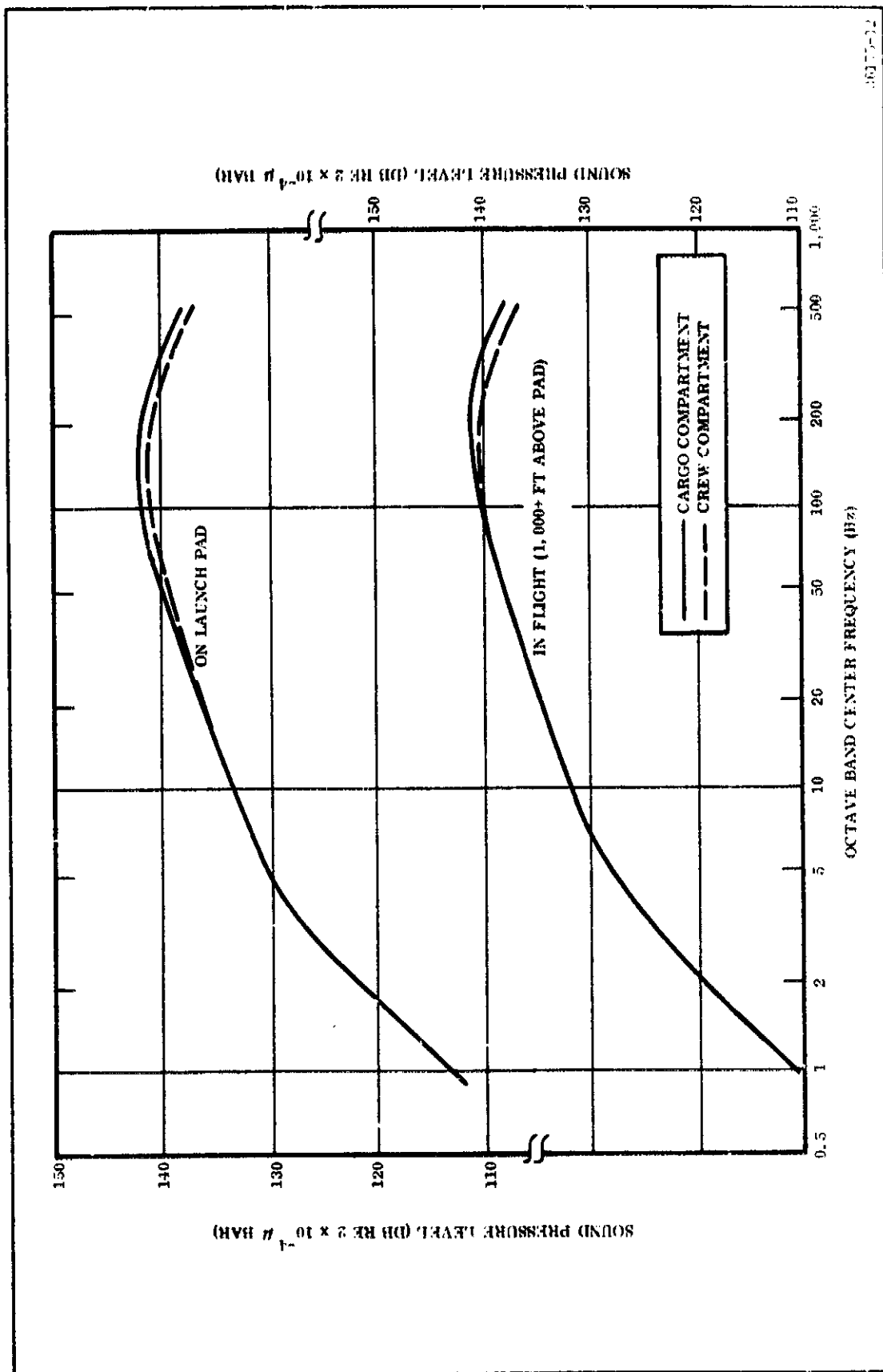


Figure 6-10. External Acoustic Environment, Series Burn

7.0 MANRATING OF THE SRM STAGE

Manrating for any system involves two broad considerations: the reliability of all hardware essential for mission success, and the safety of the crew in the event that mission success is no longer possible. By definition, of course, mission success includes safe return of the crew. SRM Stage reliability is discussed in 7.1. SRM Stage crew safety provisions are discussed in 7.2.

7.1 RELIABILITY

As indicated above, manrating requires knowledge of the system failure modes and probabilities (reliability) and only then can the need be evaluated for either (1) reducing specific failure probability to assure mission success, and/or (2) introducing hardware designed exclusively to protect the crew.

A failure modes and effects analysis has been conducted for the baseline 156 in. rocket motor stage (parallel burn) and add-on variations. The variations include thrust termination (TT), thrust vector control (TVC) and malfunction detection system (MDS). Subsequently, predicted failure rates are based upon related past experience with specific materials and component configurations in military application SRM's. These somewhat basic rates for component types were altered after review of past and potential failure types, significant differences in application, and identification of a method for control of each failure. The test, successes and failures for Stage I Minuteman and Poseidon, are summarized in this section. Special reliability oriented features of the SRM for Space Shuttle follow.

7.1.1 Design

1. Redundant TVC power and hydraulic systems.
2. Redundant TVC electrical control systems.
3. Redundant initiators for ordnance items with 1 w, 1 amp, no-fire provisions.
4. All components are established state-of-the-art designs.
5. Increased safety factors.
 - a. 1.2 hydrotest proof pressure over MEOP.
 - b. 1.4 ultimate strength on case aft skirt structure, and nozzle structure.
 - c. 2.0 (thickness) for nozzle ablative material.

- d. 2.0 (thickness) for case insulation.
- e. 1.5 ultimate strength interstage structure.

7.1.2 Manufacturing

Added quality assurance practices.

- 1. 100 percent inspection of significant design characteristics (no sampling).
- 2. Manned flight awareness promotion program and hardware identification (unique symbology for SRM acceptance stamps, paper and hardware).
- 3. More rigorous requirements for certification of tooling, processes, and personnel.

7.1.3 Testing

- 1. Proof test above MEOP.
- 2. Environmental testing for production qualification of all hardware.

The data from appropriate portions of Minuteman, Poseidon, and Genie production motors were used to provide a reliability estimate for their counterpart on the 156 in. SRM. A summary by major components provides an impressive cumulative experience record. Stage I Minuteman motors provide an excellent data base because of (1) the large number of motors tested; and (2) the case, propellant, liner and flap insulator are of the same materials as will be used in the Shuttle SRM Stage. The combined experience of Poseidon Stages I and II provides a comparable data base for the submerged, ablative insulator nozzle. The S & A, Pyrogen igniter ignition system, common to Minuteman and Poseidon motors and many other SRM's has never failed to function. The SRM Pyrogen igniter propellant, TP-II1016, is used in the Stage I Minuteman motor. The experience drawn upon here is limited to those data of which the Wasatch Division of Thiokol has had first-hand knowledge, and can thus vouch for its accuracy.

To provide a frame of reference for viewing and judging the credibility of the reliability assessment of the SRM, the failures of Thiokol furnished components of the Stage I Minuteman are summarized. The motor has a tapered thread, screw-on aft closure with four nozzles, gimballed forward of the throat. The nonredundant flight control system was provided by another contractor. The static and flight test propulsion failures have occurred on earlier configurations. No propulsion failures have occurred in the current configuration, Wing VI (RIP) in production since 1965.

The failures of these earlier versions fall into the following groups.

1. Burnthrough at the splitline (at the gimbal joint) of the nozzle (4). The Shuttle SRM Stage has no splitline or similar discontinuity to disturb gas flow through the nozzle.
2. Aft closure insulation ejection or burnthrough (5). The four port closure required nonsymmetrical insulation design to accommodate the gas exposure times and velocity gradients.
3. Aft case burnthrough (1). Several early cases utilized lightweight aft case insulation. A subsequent change to heavier insulation eliminated the marginal performance and there have been no subsequent failures.

The most relevant experience in terms of materials and design are reviewed for the major SRM components.

7.1.4 Ignition

Thiokol serves as the principal contractor for the S & A device used on all three stages of the Minuteman. While the bench tests for acceptance and recycle have revealed nonspecification performance resulting in rejection for rework, accepted S & A's have neither failed to fire on command nor failed by firing when not commanded. Similarly, although the Pyrogen igniter has in a few rare instances performed outside specification limits for mass discharge rate, a production Pyrogen igniter has never failed to ignite the motor grain or contributed to motor overpressure.

<u>Item</u>	<u>Tests</u>	<u>Failures</u>
S & A		
Stages I, II, III Minuteman	2,106	0
Pyrogen Igniters		
Stage I Minuteman	890	0
Poseidon Stage I	94	0
Igniter Propellant		
Stage I Minuteman	890	0

7.1.5 Loaded Case

The D6AC metal case experience with Stage I Minuteman supports the SRM case material selection. It is recognized that except for basic cylinder fabrication techniques, there is a major difference in the manufacture and assembly of the case for the 156 in. SRM; in addition to being much larger, it is segmented. Although there will be specific controls to assure compliance with every unique aspect of the 156 in. case, hydroproof test of each case provides the final test for assuring its reliability.

Hydrotest, as a production acceptance criterion for the D6AC cases, has been an unqualified success. The Stage I Minuteman has never experienced a structural failure of the motor case in a motor firing. The more severe hydrotest requirements for the 156 in. SRM, 1.2 over MEOP, will provide additional reliability assurance.

The TF-H1011 propellant used in Stage I Minuteman since program initiation has never failed to perform. There have been a few rare excursions beyond specification limits, but there have been no failures. The deviations were isolated to firings following exposure to environmental extremes.

The Stage I Minuteman has never experienced a failure attributed to the UF-2121 liner. Similarly, the silica filled NBR insulator used in the forward and aft case split flaps of the Stage I Minuteman has not experienced a failure. The aft case insulator failure cited above was experienced in the molded aft case segments which will not be used in the 156 inch.

<u>Item</u>	<u>Tests</u>	<u>Failures</u>
Case		
Stage I Minuteman (D6AC)	861	0
Propellant		
Stage I Minuteman (TP-H1011)	850	0
Liner		
Stage I Minuteman (UF-2121)	603	0
Internal Insulation		
Stage I Minuteman	838	0

7.1.6 Nozzle

The nearest equivalent experience in terms of configuration and materials has been in the Poseidon Stages I and II. The Thiokol designed Stage I nozzle has never experienced either marginal performance or failure. Stage II experienced a nozzle failure, and the design (responsibility of another contractor) was modified to match the Stage I design, which precludes gas flow behind the insulator.

TVC is provided via a flexible bearing between the nozzle and the case. The bearing is fabricated from alternate layers of rubber and metal. The metallic shims are sections of spheres, each with different radii. The stacked shims in the assembled bearing flex about a common center. The severe product acceptance functional test, analogous to case hydrotest, eliminates marginally performing bearings. Each bearing is axially loaded, exercised through a severe duty cycle, and pressurized. No instance of marginal performance or failure has occurred in the bearing production program.

<u>Item</u>	<u>Tests</u>	<u>Failures</u>
Nozzle		
Poseidon		
Stage I	91	0
Stage II	92	1
Flex Bearing	183	0

The redundancy provided by the TVC system design through two tandem actuators, each with redundant hydraulic power, and hydraulic and electrical control, provides an estimated reliability level comparable to other components in the SRM. Without redundancy, TVC systems have characteristically been a limiting item in reliability. The proposed hydraulic power and control design, used in the Concorde SST for emergency flight control, provides for automatic switchover to the backup system. The tandem type actuators are commonly used on large aircraft. However, Thiokol has no comparable firsthand experience in terms of similarity of design and number of tests.

These basic SRM unique items provide a real supporting experience base for confidence in the reliability potential of 156 in. SRM. The hardware not described above such as skirts, cone and interstage, are common, though not identical, to either SRM or LRM, except for the thrust termination and MDS. Thrust termination and MDS do not, of course, contribute to mission success but do support crew safety. Thrust termination is routinely performed on upper stage SRM's. Current applicable Thiokol experience includes production of the Third

Stage Minuteman. The six port, fiberglass dome mounted system is more complex and exacting in its simultaneity and quality of the porting requirements than will be necessary for the 156 in. SRM. No failures of the system have occurred on motor tests or reliability testing.

<u>Item</u>	<u>Tests</u>	<u>Failures</u>
Thrust Termination		
Third Stage Minuteman (Thiokol cognizant only)		
Motor Tests	21	0
Reliability Tests (2 port)	598	0
Lot Acceptance Tests	20	0
Qualification Tests	15	0

A summary of the predicted reliability for the 156 in. SRM is shown in Table 7-1.

7.2 CREW SAFETY

A review of potential failures vs time has identified the need to provide the following types of information to the crew to permit better judgments regarding possible abandonment of the primary or lesser alternate missions. Combustion chamber pressure sensors to:

1. Provide assurance that liftoff thrust levels have been achieved, before holddown release.
2. Indicate marginal thrust.
3. Indicate critical thrust loss.
4. Indicate unacceptable thrust difference between motors.

The principal modes of failure are shown on the failure modes analysis record. These SRM modes are discussed from the viewpoint of their threat to the mission and the possible methods of assuring crew safety.

TABLE 7-1
PREDICTED RELIABILITY FOR ONE SRM
AND ATTACH STRUCTURE

	<u>Reliability</u>
Loaded Case Assembly	
Case	0.9998
Internal Insulation	0.9998
Liner	0.9998
Propellant	0.9999
Ignition Assembly	
Safe and Arm Mechanism	0.9999
Pyrogen Igniter	0.9999
Nozzle Assembly	
Nozzle Structure	0.9998
BASIC MOTOR	0.9989
Thrust Vector Assembly	
Flexible Bearing	0.9998
Thrust Vector Control	0.9999
MOTOR WITH TVC	0.9986
Supporting Structural Hardware and Auxiliary Systems	
Attach Structure	0.99990
Forward Skirt and Nose Cone	0.99995
Aft Skirt	0.99995
Electrical, Power and Distribution	0.99990
Thrust Termination System	0.99990
MOTOR WITH TVC AND ATTACH STRUCTURE	0.9982

7.2.1 Failure Modes

7.2.1.1 Chamber Burnthrough

Failure may result when the insulator and/or chamber wall are exposed prematurely. Premature exposure results from a structural failure in the propellant or propellant/liner. The simplicity of the grain design, that is center perforate with generous stress relief flaps, greatly reduces the probability of a generative failure of the propellant/liner. The potential for grain failure is discussed more fully under overpressurization. The installation of an adequate burnthrough sensor system would require 100 percent coverage of case bonded portions of the internal insulator. A study report by General Tire and Rubber Company, R & D Center, Report No. 550, dated January 1967, indicates that the operations necessary to obtain the tolerances for laminar layup of the sensor grids in the insulation will increase the cost of fabrication by at least 200 percent. Because the sensor must be so extensive and involves so many junctures, i.e., at each preformed insulator segment, it is vulnerable to failure via initiation of a false signal. Although these risks have not been analytically evaluated to determine the incremental increase in crew safety obtainable from a burnthrough sensor system, it is believed that via overdesign and the application of specific, exacting operations controls and quality assurance methods of the type that would be absolutely necessary with the installation of the sensor system, safety of the crew will be best assured. Thus, Thiokol will invest the equivalent extra resources into assuring the inherent reliability and quality of the insulator installation, transportation, handling, and preassembly inspection.

7.2.1.2 Overpressurization

This propellant related failure mode has an extremely low probability of occurrence. This is particularly true for larger motors as the sensitivity to increase in grain surface area exposure decreases with increased motor size. Failure via overpressurization has never occurred in Thiokol motors 60 in. in diameter or larger. Examination of the SRM grain reveals a basis for even greater assurance that overpressurization will not occur. The basis for overpressurization can be examined from two circumstances.

1. An initially large crack, separation, etc, to provide the additional propellant surface area necessary for case rupture.
2. A lesser crack, separation, etc, which propagates to sufficient area to cause case rupture.

The additional grain surface area necessary to cause the first circumstance needs to be in the order of 145,000 sq in. at $T + 0.5$ sec and 120,000 sq in. at P_{max} , approximately 44.2 sec. To further illustrate the enormous size of such

a grain defect, complete unbonding of one segment at ignition would only result in P_c max of 1,290 psia. The point is that such defects could not escape routine visual inspection, and of course, the grain will also be inspected by NDT methods.

A grain surface flaw such as a sharp bottomed scratch or crack in TP-H1011 propellant will not propagate during burning time. There are several contributing reasons.

1. The static gas forces acting upon the viscoelastic grain, i. e., surface pressure, closes rather than opens grain surface fractures, thus reducing the stress concentration effects around the defect. Gas flow effects at the grain surface are erosive.
2. The grain loading effects, because of case expansion at ignition, are less with steel than with glass cases.
3. The smooth CP core cavity reduces the grain surface stress approximately 8 percent under those stresses resulting from a star section cavity.

As cited in the discussion of the case, the reliability inherent to the grain design (materials, configuration and safety factor), and the added assurance provided by process controls and testing, eliminates the need for special crew safety provisions.

A related fact, but incidental under the circumstances, is the available warning time for either case rupture (for case weaknesses) or overpressurization (for non-case related weaknesses). The available warning time for failure by overpressurization could be as low as 20 msec which is not sufficient for automatic verification and response by the MDS. Warning time in the order of 0.25 sec is required for the MDS. Ballistic anomalies pose a more realistic threat. These may result from variation in propellant burning rate or exposure, which results in thrust imbalance between the SRM's. A shuttle system attitude rate sensor with automatic provisions for SRM's termination will probably be necessary for several other potential flight control system failures. This emergency system would also fulfill crew safety needs for SRM-created intolerable turning moments.

7.2.1.3 Thrust Loss

A decay in thrust from one SRM could result from:

1. Throat ejection.
2. Nozzle ejection.
3. Burnthrough.

In the parallel configuration, the effects of thrust decay would become evident as a sustained uncommanded thrust vector correction and a chamber pressure decay. If the uncorrectable portion of the thrust vector resulted in attitude rate change exceeding the orbiter system sensor limit, a thrust termination command would be initiated for both SRM's. The consequences of the loss of thrust, from the above cited causes, is a function of the time until motor burnout. A review of nozzle failures, in the early history of Minuteman nozzles (a gimbal section near the throat), reveals that nozzle failure occurred late in motor action time. Because the mission effects of thrust loss are less severe, the later the occurrence, the greater threat the overturning moment becomes to the probability of continuing the mission. The benefits of sensors designed to detect the specific causes of the gross symptom are not obvious. However, because chamber pressure correlates directly with thrust, sensors designed to relay the state and direction of chamber pressure would be useful. A continuous range pressure indicator showing discrete pressures and rate change, rather than a limit type activating a panel light, would provide potentially more useful information. However, a single panel display, indicating differential chamber pressure (parallel burn), may be more reasonable in terms of providing meaningful information to the crew. The differential pressure need not be tailored to the pressure time envelope. And, the one instrument is meaningful through SRM propulsion. Significant differences in thrust because of no thrust, excessive, or insufficient thrust become significant first in terms of flight control rather than total mission thrust. Three sensors per SRM with a majority vote requirement for each SRM output will increase the reliability of the MDS.

Summary crew safety recommendation for the SRM's follow.

1. A three sensor majority vote analog output from each SRM.
2. A crew display, differential pressure indicator receiving pressure inputs from each SRM.

7.3 PRELIMINARY FAILURE MODE ANALYSES

A failure mode analysis has been conducted for each component and add-on item of the baseline SRM. These preliminary analyses are concerned only with the major functional characteristics, not the as-yet-undefined internal workings of the components or assemblies. Listed below are the components and add-on items for the baseline 156 in. SRM for which preliminary analyses have been conducted.

1. Case (segmented D6AC steel).
2. Internal Insulation.
3. Liner.

4. Propellant (TP-H1011).
5. S & A Device.
6. Pyrogen.
7. Thrust Termination System. *
8. Nozzle (fixed).
9. TVC System. *
10. Flex Bearing. *
11. Attach Structure.
12. Forward Skirt and Nose Cone.
13. Aft Skirt.
14. Electrical, power and distribution system.

The preliminary analysis charts contain eight columns, all of which are utilized with the intent of presenting a comprehensive record of the analysis. Following are descriptions of each column in the failure mode charts.

Column 1, entitled "Component," identifies the component or assembly to be analyzed.

Column 2, entitled "Function," describes the purpose and special actions of the particular component or assembly.

Column 3, entitled "Component Failure Mode and Reasons for Component Failure," states the anticipated characteristic failure modes and enumerates reasons for their respective occurrences.

Column 4, entitled "Influence on System," surmises the impact of the possible failure with respect to the entire Space Shuttle vehicle.

Column 5, entitled "Component Failure Rate," predicts the failure rate of the component or assembly.

Column 6, entitled "Effect on System," assesses the degree of debility of the Space Shuttle vehicle with respect to the failure mode of the component or assembly.

*Add-on components for baseline SRM.

Column 7, entitled "Reliability," cites the effective reliability of the component or assembly and is one minus the product of Column 5 and Column 6.

Column 8, entitled "Control Methods," specifies fabrication, inspection and test methods to assure failure occurrence probability not in excess of the rates cited in Column 5. A method is cited for each potential reason for component failure.

TABLE T-2

REVISION 1

PRELIMINARY RELIABILITY ANALYSIS RECORD

PRELIMINARY RELIABILITY ANALYSIS RECORD				DRAWING NO. TUL 13332	DATE 1-26-72	SHEET 1 OF 1	
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE DATE	EFFECT ON SYSTEM	COMPONENT RELIABILITY	CONTROL METHODS
Case (Segmented)	Functions as a principal structure for auxiliary systems and as a container for the solid propellant. During launch and flight it also serves as a pressure vessel and transmits thrust to the core attachment structure	1. Case fails to function as a pressure vessel. a. Rupture a.1 Structural a.1.1 Defective material a.1.2 Faulty Segment fabrication and case assembly a.1.3 Out of tolerance a.1.4 Handling and Transportation damage a.1.5 Vibration, shock and acceleration	I. Loss of thrust Mission abort Crew safety In parallel configuration there exists the possibility of affecting an imbalance to the flight of the Space Shuttle vehicle.	-0002	1.0	90.9998	a.1 Q. A. review of drawings prior to release for quality requirements. Hydroburst during development of two forward, two center and two aft segments to verify safety factors. a.1.1 Metallurgical monitoring during material processing and segment fabrication. Vendor certified chemical composition and heat treatment data.
		*Component reliability is concomitant with the requirement of a total life cycle of ten missions.					*a.1.2 Rigorous adherence to fabrication and assembly procedures. Certified vendor assembly methods. Certified operators and inspectors. Stringent Q.C. inspection. Ultrasonic, magnetic particle testing and hydro-testing by vendor. Vendor data review. **a.1.3 Deviation control. Complete inspection including that by certified TCC inspectors. Hydro-proofing each segment. Receiving inspection at TCC and launch site. MRB for discrepancies according to Mil. Std. 199.
							PMEA TH&S CL&F TOTAL

Shuttle Motor - Baseline SRM Stage

PRELIMINARY

REVISION 1

TABLE 7-2 (Contd)

PRELIMINARY RELIABILITY ANALYSIS RECORD								DRAWING NO. TUL 13332		DATE 1-26-72		SHEET 2 OF	
1. 1.4.													

TABLE F. 7-2 (Cont)

PRELIMINARY RELIABILITY ANALYSIS RECORD				ISSUE NO. TUL 13332	DATE 1-26-72	SHEET 3 OF
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	CONTROL METHODS
156 Inch Space Shuttle Motor - Baseline SRM Stage						
Insulation	Affords protection to the case from combustion heat.	I. Insulation fails to provide a thermal barrier. a. Burn through a.1 Non-conformance to specification a.2 Excessive erosion a.3 Faulty installation b. Structural failures b.1 Chemical change b.2 Overstress b.3 Shock (thermal/mechanical) b.4 Faulty installation	I. Case failure Possible mission failure	.0004	0.5	I. Q. A. review of drawings and specifications to ensure adequate inspection requirements. Vendor process data review. Receiving inspection. Spot checks for specified thickness. Same controls as for a.1. a.1
Internal: Insulation bonds heat and aft and forward segment flaps)		II. Flap failure a. Burn through b. Structural c. Unbonding c.1 Faulty installation	II. Improper combustion affecting burn rate. Deficient or excessive thrust. In parallel configuration there exists the possibility of affecting an imbalance to the flight attitude of the Space Shuttle vehicle.			a.2 Review static test data and plot erosion points. Check cases for erosion before refurbishment. a.3 Certified procedures, operators and inspectors. Visual inspection. Ultrasonic inspection after loading of segments. b. Visual inspection of loaded segments at launch site. b.1 Weather protection, insulated shrouds. Relative short time span to firing precludes aging deterioration. b.2 Dependent upon propellant behavior. b.3 Visual inspection after road testing during development. b.4 Same as for a.3. II. Same controls as for I.
ASB-SI-NPR						

PRELIMINARY RELIABILITY ANALYSIS RECORD

TABLE 7-2 (Cont.)

REVISION 1

PRELIMINARY RELIABILITY ANALYSIS RECORD						DRAWING NO. TUL-13332	DATE 1-26-72	SHEET 4 OF 8
156 Inch Spare Shuttle Motor - Baseline SRM Stage								
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPUTED FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	COMPONENT RELIABILITY	Loaded Case Assembly	
Liner RF212 Propellant to Liner Bond (System)	To maintain propellant to insulation bond under all environment conditions and to prevent any possibility of propellant burning on the bonded surfaces.	I. Apparent high burn rate/MEOB a. Excessive burning surface due to failure of liner to bond to the propellant or the insulator. a.1 Inadequate cleaning a.2 Defective liner material: a.3 Defective liner application a.4 Post liner application contamination	I. Motor case failure Failure to meet thrust envelope Failure to meet ignition envelope	.0004	.5	.9998	a.1	Q.A. review of drawings and specifications to ensure adequate inspection requirements. Certified operators and inspectors, stringent Q.C., Standardization by batch size. a.2 Process instruction on and monitoring of liner preparation and application. Visual inspection and ultrasonic inspection after loading segments a.3 Case sealed from environment after liner application. a.4
								PMB A THS S CL & F TOTAL

TABLE T-2 (Cont)

REVISION 1

PRELIMINARY

RELIABILITY ANALYSIS RECORD

COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPUTED COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	CONTROL METHODS
Propellant TP-71101	Provides the gaseous combustion products at a predictable and controlled pressure and rate which will produce a specified thrust or total impulse when accelerated through a nozzle. The geometric configuration of the burning surface is critical to the function and is treated as part of this component assembly.	I. High burn rate (real or apparent) a. Excessive burning surface. a. 1 Cracks due to excessive handling loads. a. 2 Cracks due to high modulus. a. 3 Propellant slump-low modulus. b. Weighing or control test errors. c. Voids due to air entrapment. d. Grain design results in excess gas velocities. e. Excessive propellant temperature.	*I. Possible motor case failure and failure to meet thrust envelope.	.0001	1.0	.9999
		II. Low burn rate/slow ignition a. Weighing or control test errors. b. Reduced burning surface b. 1 Propellant slump b. 2 Low modulus b. 3 Humidity exposure	*II. Failure to meet thrust envelope.			a. 2
		III. Low Total Impulse a. Low Isp a. 1 Defective raw materials b. Incorrect propellant weight.	*III. Failure to reach stage velocity requirement.			a. 3 b.
		IV. Preignition (auto-ignition) a. Exposure to temperatures in excess of 420°F.	IV. Safety hazard to crew and vehicle.			c. d.
			*In parallel configuration there exists the possibility of effecting an imbalance to the flight attitude of the Space Shuttle vehicle.			e. II. b. 1 b. 2 b. 3
						Visual inspection and x-ray during production. Same as the above after handling tests during development. Post process inspection of each segment to verify modulus, stress and strain. Stress analyses of grain configuration. Certified process methods, operators and inspectors. Controlled curing process. Same as for I. a. 2 Calibration of weighing equipment. In-process testing of each segment, for burn rate, total solid and HB/ECA ratio. X-ray Detection and rectification during development phase. Same as I. d. Same as for I. a. 3 Same as for I. a. 3 Non-sensitivity to humidity determined from past weapon systems experience.
						PMSA THAS CL&F TOTAL

TABLE 7-2 (Cont)

REVISION 1

PRELIMINARY
RELIABILITY ANALYSIS RECORD

156 Inch Space Shuttle Motor - Baseline SRM Stage

PRELIMINARY RELIABILITY ANALYSIS RECORD				DRAWING NO. JUL 13332	DATE 1-26-72	SHEET 6 OF
156 Inch Space Shuttle Motor - Baseline SRM Stage				Loaded Case Assembly		
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	CONTROL METHODS
Propellant TP-H1011 (Continued)						III. Vendor data review. a.1 Raw materials standardization. Ballistic property tests on subscale samples. Shelf life control. b. Weighing of each segment before and after loading. IV. Protection from extreme conditions precludes exposures to such temperatures.
				PM2A TH2S CL2F TOTAL		

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REVISION 1

TABLE T-2 (Cont)

PRELIMINARY
RELIABILITY ANALYSIS RECORD

156 Inch Space Shuttle Motor - Baseline SRM Stage

COMPONENT		FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	REPAIR ON SYSTEM	COMPONENT RELIABILITY	CONTROL METHODS
Nozzle (Exit cone, nozzle throat)	1.	Receives the gases from nozzle entry and expands them to the motor exterior within design flow and erosion profile rates.	a. Damage to or destruction of nozzle a. 1 Structural failure a. 2 Nonconformance to specifications a. 3 Defective material a. 3 Faulty assembly b. Environmental b. 1 Vibration b. 2 Thermal or mechanical shock b. 3 Chemical change b. 4 Stress	Reduced thrust and possible loss of flight control.	.0002	1.0	*.9998	1. a. Q.A. review of drawings and specifications to ensure adequate inspection requirements. Quality proof testing to ensure design integrity. Vendor data review. Control against deviation. Complete inspection. Certified operators and inspectors. Performing inspection by TCC and aft segment inspection at launch site. NHA for discrepancies. Two nozzle metal parts will be hydroburst during development to ensure structural integrity. a. 2 Metallurgical monitoring during material processing and nozzle fabrication. Vendor certified chemical composition and heat treatment data. a. 3 Certified vendor process and fabrication methods. Certified operators and inspectors. b. 1 Board course and risk coupling tests during development. b. 2 Nonsensitively ensured through development. b. 3 Same as for b. 2. b. 4 Same as for b. 2. Destructive pressure testing during development.

*Component reliability is concomitant with the requirement of a total life cycle of 10 missions, applicable only to the metal parts.

TABLE
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PRELIMINARY
RELIABILITY ANALYSIS RECORD

TABLE 7-2 (Cont)

REVISION 1

156 Inch Space Shuttle Motor - Baseline SRM Stage		DRAWING NO. TUL 13332		DATE 1-26-72		SHEET B	
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASON FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM	Ignition Assembly	CONTROL METHODS
Pyrogen	Provides necessary heat energy to ignite the main propellant surfaces over a sufficient area to sustain burning and meet a specified thrust time envelope.	<p>I. Failure to ignite or sustain burning of the main motor propellant.</p> <p>a. Defective materials and/or composition</p> <p>b. Propellant degradation</p> <p>II. Possible rupture of pyrogen case because of excessive pressures.</p> <p>III. Auto-ignition</p> <p>a. Improper or defective propellant raw materials.</p> <p>b. Deterioration due to age or environment.</p> <p>c. Incompatibility with other materials.</p> <p>d. Voids, inclusions, porosity, cracks in propellant.</p> <p>e. Case bond discontinuities</p> <p>f. Poor physical properties</p> <p>g. Exposure to temperatures exceeding 700°F.</p>	<p>I. Insufficient or no thrust for lift off abort mission at pad.</p> <p>II. Failure to meet ignition time and thrust envelopes.</p> <p>III. Risk of motor case failure.</p> <p>IV. Crew safety.</p>	.0001	1.0	.9999	<p>a. Q. A. review of drawings and specifications to ensure adequate inspection requirements.</p> <p>Raw materials analysis.</p> <p>Standardization of raw material lots. Shelf life control. Calibration of weighing and test apparatus. Q. C. record keeping. Stress analysis of grain configuration.</p> <p>X-ray</p> <p>Lot sampling for ballistic acceptability.</p> <p>Propellant batch tests for tensile properties, chemical contents.</p> <p>b. Same as for I. a.</p> <p>II. Same as for I.</p> <p>III. Same as for I.</p> <p>Weather protection.</p>
Secondary		Igniter case/adaptor assembly fails to withstand combustion chamber pressures during motor action time.	Secondary				
I. Igniter case/adaptor assembly fails to withstand combustion chamber pressures during motor action time.		<p>a. Hot gas leakage at igniter flange/adaptor/motor case interfaces.</p> <p>a.1 Defective seal and packing materials fabrication and installation.</p> <p>a.2 Seal degradation from handling and storage effects</p> <p>b. Structural failure of igniter chamber flange/adaptor.</p> <p>b.1 Insufficient material strength</p> <p>b.2 Insufficient thickness</p> <p>b.3 Induced cracks from handling or transportation</p> <p>b.4 Weak bolts or over torquing.</p>	I. Pressure vessel rupture. Mission abort.				<p>Secondary</p> <p>I. Certified fabrication and assembly procedures.</p> <p>operators and inspectors.</p> <p>Visual inspection</p> <p>X-ray</p> <p>Torquing control</p> <p>Batch sample testing</p> <p>b. Same as for I. a.</p>

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TABLE 7-2 (Cont)

REVISION 1

PRELIMINARY
RELIABILITY ANALYSIS RECORD

Add Cns to the 156 Inch Baseline SRM

COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	IGNITION ASSEMBLY EFFECT ON SYSTEM RELIABILITY	TEST ID	TEST DATE
Thrust-Termination System (Linear Charges) explosive manifold, S&A	To cut circular holes in the forward dome inside the thrust termination stacks, thereby terminating the effective thrust of the SRM.	I. Partial or no thrust termination. a. Defective linear shaped charges. a.1 Charge unbonding b. Defective explosive leads c. Defective manifold d. S&A Malfunction d.1 Defective detonators d.2 Broken or corroded switches d.3 Faulty assembly d.4 Defective or broken parts d.5 Fungus or contaminated moving parts/circuits d.6 Electrical armature failure II. Inadvertent arming and firing a. Electrical short between firing circuit and arming device. b. Excessive temperature.	I. Inability to effectively cease motor operation. Possible orbiter control difficulty. Prolonged staging operations. II. Hazard to crew and vehicle.	0.0001	1.0	1.0000	1. Q.A. review of drawings and specifications to ensure adequate inspection requirements. Potency and proven record of this item precludes failures. Visual inspection at launch site. Qualification testing. Rigorous developmental testing on mock-ups. Material acceptance control and receiving inspection. a. Same as for I. A. Redundant systems: three initiation points per linear charge; six explosive leads per manifold. c. Visual inspection. Material acceptance criteria. d.1 Redundant system two detonators per S&A. d.2 (et seq.) Visual inspection certified operators, inspectors tooling and processing. Material acceptance control. Board course and trail coupling tests during development. Weather protection. Demonstration during development by firing TTS at 50% of propellant weight. II. Same as for I. d. 2 a. Protection from extreme conditions.

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TABLE 7-2 (Cont)

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RELIABILITY ANALYSIS RECORD

Add Ons to the 156 Lch Baseline SRM

COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	Vehicle Assembly CONTROL NETWORK
Thrust-Vector Control Tandem hydraulic actuators, 2 APU's).	Provides pitch and yaw control by changing the angle of the thrust axis.	I. Insufficient or no hydraulic actuation. a. Structural a.1 Defective parts a.2 Nonconformance to specifications a.3 Improper assembly a.4 Bearing and/or mounting point failure b. Hydraulic fluid b.1 Density and operating temperature change b.2 Fluid degradation c. APU malfunction d. Voltage regulator failure e. Defective gas generator f. Speed control failure g. Turbine and blades failure h. Loss of pressure control i. Faulty lines and fittings j. Malfunction of servo control unit II. Deficient actuation rates. (Same reasons as for I)	i. Loss of thrust vector control. Possible mission abort. Crew Safety II. Improper flight attitude control rate.	.0001	1.0	a. Q. A. review of drawings and specs. to ensure adequate inspection criteria. Rigorous acceptance criteria. Certified operators and inspectors. Non-destructive testing to ensure required operational capability. Pressure actuation testing after assembly. b. Fluid is selected and tested to ensure compatibility with operating conditions. c. Redundant systems: 2 APU with independent hydraulic and servo systems. c. (et seq.) Qualification of design during development. Certified operators and inspectors. Operation cycle testing. Board course and coupling tests during development. Visual inspection at launch site.

*Component reliability is concomitant with the requirement of a life cycle of 5 missions for the APU.

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TABLE 7-2 (Cont)

Revision 1

PRELIMINARY
RELIABILITY ANALYSIS RECORD

PRELIMINARY							
RELIABILITY ANALYSIS RECORD							
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	CONTROL METHODS	DATE
Flex-Bearing	Provides structural restraint for movable nozzle. Permits omniaxial movement within the designed deflection limits.	I. High actuation times due to insufficient flexing. a. Structural a. 1 High modulus of rubber a. 2 Deterioration of rubber due to aging a. 3 Defective shims a. 4 Faulty assembly	I. Loss of or impaired thrust vector control. Prolonged TVC operating time. Crew safety.	.0004	.9998	I. Acceptance tests for modulus. Visual check for unbond on each bearing. Dimensional check on each bearing. a. 2 Storage life control and materials storage life requirements to guard against aging. a. 3 Acceptance tests for shims. Certified heat treatment data records. a. 4 Certified loading, operators and inspectors. Pressurized activation testing of each bearing.	1-25-72
		II. Failure to withstand pressure loads during motor action time. a. Structural (Same reasons as for I). a. 1 Unbonding between steel shims and rubber b. Non-conformance to specifications during assembly. c. Combustion gas leakage d. Attachment ring failure e. Mounting bolt failure	II. Chamber pressure and thrust decay. Possibility of affecting imbalance to the flight attitude of the vehicle.			II. Same as for I. a. 1 Periodic dissections of bearings to check for unbonding. b. Same as for I. a. 4 Discrepancies subject to MRE. c. Pressure acceptance testing d. Chemical and physical properties data records of steel rings. Pressurized exertion tests for each bearing to ensure specified torque levels, wall point and maximum deflection. Batch quality control. e. Bolt torquing control.	
PMS A THRS CLIF TOTAL							

FORM 7-70 (23) REV. 1-65

TABLE 7-2 (Cont)

PRELIMINARY RELIABILITY ANALYSIS RECORD			156 inch Space Shuttle Motor - Baseline SRM Stage			REVISION 1		
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	PARALLEL CONFIGURATION EFFECT ON SYSTEM	COMPONENT RELIABILITY	CONTROL METHODS	
Attach Structure Forward and aft	Provides physical connection between SRM and Space Shuttle vehicle. Conveys to the Space Shuttle vehicle the effective thrust generated by the SRM.	I. Detachment of SRM from Space Shuttle vehicle. a. Structural a. 1 Non-conformance to specifications a. 2 Defective materials a. 3 Bolt failure a. 4 Incorrect torquing a. 5 Environmental effects due to vibration, shock and stress a. 6 Failure due to high stress areas.	Mission abort. Possible hazard to crew.	0.0001	1.0	0.9999	1. Q.A. review of drawings and specifications to ensure adequate inspection requirements. Certified process methods, fabrication, operators and inspectors. a. 2 Vendor supplied chemical properties and heat treatment data records. Magna fluxing Stress Analysis Load testing beyond required operational limits. a. 3 Same as for I.A. 2 a. 4 Q.C. inspection and certification of each joint. a. 5 Detection and rectification during development programs. Load and fatigue testing. a. 6 Same as for I.A. 5.	
		II. Bending of attach stays. (Same reasons as for I)	Mission abort. Possible loss of flight control. In parallel configuration, there exists the possibility of affecting an imbalance to the flight attitude of the Space Shuttle vehicle.				II. Two over pressure rigidity tests for qualification program. Four tests to run in conjunction with attach structure to verify design integrity. Ten static tests which will convey thrust load from nose cone via the attach structure.	
							PMIA TMS CLS TOTAL	

TABLE 7-2 (Cont.)

REVISION 1

PRELIMINARY RELIABILITY ANALYSIS RECORD				156 Inch Space Shuttle Motor - Baseline SRM Stage				DRAWING NO. 13405		DATE 2-1-72		REVISION 1	
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	CONSEQUENT FAILURE RATE	EFF CT ON SYSTEM RELIABILITY	Parallel Configuration Components		CONTROL METHODS					
Forward Skirt and Nose Cone Assembly	Forward skirt provides structural support for the aerodynamic nose cone. Provides handling attachment points, auxiliary component mounting locations and protects the auxiliary equipment from external aero loads. Also incorporates the thrust termination stacks. Nose cone protects the auxiliary equipment from external aero loads and affords aerodynamic efficiency to the forward end of the SRM. Transmits thrust from forward skirt of motor to attach structures.	1. Failure to withstand aerodynamic loads. a. Structural a.1 Non-conformance to specifications a.2 Defective materials a.3 Environmental effects due to vibration, shock and stress. a.4 Transportation and handling damage	Reduced aerodynamic efficiency. Damage to auxiliary equipment and possible loss of operation, thereof. In the event of an emergency requirement for thrust termination, TT system may be inoperative. Possible additional threat to crew safety.	.0001	0.5	1. 99995	1. a.1 Q. A review of drawings and specifications to ensure adequate inspection requirements. Certified process methods fabrication, operators and inspectors. a.2 Vendor certified chemical properties and heat treatment data records. Magna fluxing. Load testing. TCC Q. C. representative at launch site. a.3 Detection and rectification during development program. 15 qualification flight tests.) Discrepancies subject to MRR. Two over pressure rigidity tests for qualification program. Four tests to run in conjunction with attach structure to verify design integrity. Ten static tests which will convey thrust loads from the nose cone via the attach structure. a.4 Visual inspection and receiving control criteria at launch site.						
PMA THS CLF TDA													

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TABLE 7-2 (Cont)

REVISION 1

PRELIMINARY
RELIABILITY ANALYSIS RECORD

PRELIMINARY RELIABILITY ANALYSIS RECORD									
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM	COMPONENT RELIABILITY	CONTROL METHODS	DATE	BY
Alt Skirt and Support Assembly for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	Provides structural support for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	1. Failure to support Space Shuttle vehicle assembly by providing a rigid base.	Possible collapse of Space Shuttle vehicle. Mission abort at launch pad. Safety hazard to crew and vehicle.	.00005	1.0	.00005	2. A. review of drawings and specifications to ensure adequate inspection requirements. Certified process methods, fabrication, operators and inspectors. Vendor certified chemical properties and heat treatment data records. Magna fluxing. Load testing of each assembly beyond required operational limits. Load and rigidity tests during qualification program. TCC Q. C. representative at launch site.	2-1-72	JL
		a. Structural							
		a. 1 Non-conformance to specifications							
		a. 2 Defective materials							
		a. 3 Environmental effects due to vibration, shock and stress							
Alt Skirt and Support Assembly for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	Provides structural support for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	a. 4 Transportation and handling damage	Possible collapse of Space Shuttle vehicle. Mission abort at launch pad. Safety hazard to crew and vehicle.	.00005	1.0	.00005	2. A. review of drawings and specifications to ensure adequate inspection requirements. Certified process methods, fabrication, operators and inspectors. Vendor certified chemical properties and heat treatment data records. Magna fluxing. Load testing of each assembly beyond required operational limits. Load and rigidity tests during qualification program. TCC Q. C. representative at launch site.	2-1-72	JL
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		a. 2 Defective materials							
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		a. 2 Defective materials							
		a. 3 Environmental effects due to vibration, shock and stress							
Alt Skirt and Support Assembly for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	Provides structural support for the Space Shuttle vehicle while in the launch-ready position. Also, provides handling attachment points, auxiliary components, mounting locations and protects the nozzle and auxiliary equipment from external aero loads.	a. 4 Transportation and handling damage	Possible collapse of Space Shuttle vehicle. Mission abort at launch pad. Safety hazard to crew and vehicle.	.00005	1.0	.00005	2. A. review of drawings and specifications to ensure adequate inspection requirements. Certified process methods, fabrication, operators and inspectors. Vendor certified chemical properties and heat treatment data records. Magna fluxing. Load testing of each assembly beyond required operational limits. Load and rigidity tests during qualification program. TCC Q. C. representative at launch site.	2-1-72	JL
		a. 1 Non-conformance to specifications							
		a. 2 Defective materials							
		a. 3 Environmental effects due to vibration, shock and stress							
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		a. 1 Non-conformance to specifications							
		a. 2 Defective materials							
		a. 3 Environmental effects due to vibration, shock and stress							

 PMIA
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TABLE 7-2 (Cont)

PRELIMINARY RELIABILITY ANALYSIS RECORD		156 Inch Space Shuttle Motor - Baseline SRM Stage		Drawings TUL 13405	DATE	SHEET 16 OF
COMPONENT	FUNCTION	COMPONENT FAILURE MODE AND REASONS FOR COMPONENT FAILURE	INFLUENCE ON SYSTEM	COMPONENT FAILURE RATE	EFFECT ON SYSTEM RELIABILITY	CONTROL METHODS
Electrical, power and Distribution System. (Electrical ordnance items and distribution box, ordnance items, instrumentation enclosure, transducers, TVC distribution box, flight controls, thrust termination distribution box, power transfer switch, hydraulic power supply, ground power umbilical outlet, one battery package for instrumentation, one battery package for switching operations, stage distribution box, and malfunction detection system distribution box.	Provides electrical power, control circuitry including guidance interface, instrumentation, parameter sensing and feedback, ordnance discretes, ground electrical interface and separation and critical operations and malfunction detection interface.	I. Failure to accomplish required function a. Defective materials b. Faulty installation c. Contaminated or corroded or damaged connectors and wiring. d. Operated or degraded circuitry or wiring. e. Environmental degradation due to vibration, shock and stress. f. No or insufficient electrical power. g. Performance outside of design limits.	I. Possible mission abort or failure to complete defined mission as a result of improper thrust vector control, failure to ignite one or both motors, or ordnance items, or loss of instrumentation.	0.0001	1.0	1. Acceptance criteria. 2. Certified operators and inspectors. 3. Visual inspection, 100% operation testing after installation. 4. Weather protection. 5. Same as for I. c. 6. Inspection and testing at launch site. 7. Same as for I. c. 8. Comprehensive development program to eliminate weak design parameters.

PBA
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TOTAL

80 SYSTEM SAFETY ANALYSIS

8.0 SYSTEM SAFETY ANALYSIS

A preliminary system safety analysis has led to the development of safety requirements for the design, transportation and handling, assembly, preflight check-out, flight, and recovery of the SRM stage. Each safety requirement was developed to cope with an identified potential hazard to personnel and equipment. The safety requirements cited in the Operating Safety Analysis (Table 8-1) encompass: procedures, equipment, regulations, training, testing, identification, design safety margins, preventive maintenance, etc. This preliminary analysis record will be expanded and updated as continuing subsequent analyses reveal additional requirements. As described in the System Safety Plan, safety requirements are transmitted to the personnel who will fulfill the requirement and to the Product Assurance Program Manager who must assure their fulfillment.

The content of Table 8-1, by column, is described below.

1. Operation--The program operation to be analyzed in concise terms.
2. Task Description--Each task, step, event, and function of the operation described in sequence of occurrence (subsequent analysis will describe the task to the lowest level of detail necessary to analyze the hazards associated with the operation).
3. Criteria Facts--All known criteria concerning the operation and equipment which might affect safety; such as: energy flow, sources, and levels including pressure, voltage, and current; propellant weight and content; radar frequencies and energy levels, etc.
4. Hazards Undesirable Event--All actual or potential hazards to personnel or equipment for each task/operation (if a human error or equipment failure is possible, it is assumed to occur for analysis purposes).
5. Hazard Class--All hazards classified per the categories cited in para 3.2 of Safety Program Directive No. 1, Rev A (Class I is the equivalent of Category a).
6. Safety Requirements--Requirements in terms of procedures, processes, material, or equipment necessary to reduce or eliminate the identified hazard.

OPERATING SAFETY ANALYSIS

TABLE 8-1
Preliminary

OPERATION: GENERAL		156 DYCH SPACE SHUTTLE MOTOR	BASELINE SRM STAGE	Page 1 of 1	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Design Requirements		I. Engineering Design	Class IV		NASA Standard's ICC Specifications Vendor Requirements
	A. Under Specifications			Design considerations shall provide maximum safety to personnel and equipment.	
	B. Over Specifications			The safety considerations for personnel shall take precedence over those for equipment.	
	C. Material Deviation			Specific safety considerations for personnel which take precedence over those for equipment are identified through proper considerations of safety criteria during design stages. Personnel safety and equipment safety have a direct interface and the action of one exerts a strong effect upon the other.	
	D. Safety Sacrificed for Costs			Safety factors:	
				1. 1.2 hydrotest proof pressure over MEOP	
				2. 1.4 ultimate strength on case of skirt structure, and nozzle structure	
				3. 2.0 (thickness) for nozzle ablative material	
				4. 2.0 (thickness) for case insulation	
				5. 1.5 ultimate strength inter-stage structure	

OPERATING SAFETY ANALYSIS

TABLE 3-1 (Cont)

Preliminary

OPERATION: SRM - PREFLIGHT CHECK-OUT		156 INCH SPACE SHUTTLE MOTOR		Page 1 of 3	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
SRM - Preflight Preparation and Check-out after Space Shuttle System Has Been Erected	Autoignition has never occurred except in a motor deliberately involved in an autoignition test.	L. Pyrogen			DOD 4145.26M AFM 127-100 TCC Specifications
		A. Autoignition	Class IV		
		1. Deterioration due to age or environment		Environmental controls Visual inspection	
		2. Propellant imperfections (voids, cracks, etc.)		NDT and visual inspections	
		3. Liner/propellant or liner/case separations		NDT and visual inspections	
	In the complete history of the S & A Device, used for the Minuteman, (three stages each with an S & A Device), there has not been one incident of inadvertent arming and firing.	4. Excessive temperature exposure			DOD 4145.26M AFM 127-100
		II. Safe and Arm Devices			
		A. Inadvertent arming and firing	Class IV		
		1. Electrical short between firing circuit and arming device		Visual inspections Pre-installation check-outs Ensure that no possible thermal exists that would cause a 400 volt AC or DC short to 5kA electrical leads.	
		2. Malfunction of the launch facility monitoring and control equipment.			
	B. Prelaunch Tests	3. Human error		Certified installation and assembly operators	AFM 127-100 TCC Specifications
		4. Excessive temperature		Environmental control below 400°F.	
			Class III		

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OPERATING SAFETY ANALYSIS

TABLE S-1 (Cont)

OPERATION: Continuation of SRM - Preflight Check-out 156 INCH SPACE SHUTTLE MOTOR				Page 2 of 3
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	SAFETY REQUIREMENTS	JUSTIFICATION
		1. S&A current tests	S&A Devices shall remain in the safe position during all pre-launch component tests.	
		2. Stray voltage tests		
		C. Pre-launch Countdown Hold Status	Return all S&A Devices to the safe position if previously armed.	
		III. Thrust Termination System		TTC Specifications NASA Standards
		A. Inadvertent arming and ignition (S&A)	Class III	
		1. Excessive temperature	Visual inspections Environmental controls	
		2. Electrical short between firing circuit and arming device	Qualification testing Board course and rail coupling tests Pre-installation tests	
		IV. Final Component Installation		TTC Specifications NASA Standards
	While there have been incidents of ordnance devices being dropped and experimental drop tests conducted, no such situations have resulted in an ignition.	A. Hazards During Ordnance Installation (S&A Devices, Pyrogen, etc.)		
		1. Rough Handling	Certified operators and inspectors	
		2. Human error	Certified operators and inspectors	
		3. Ordnance dropped	NDI all ordnance containing propellant. Disassemble components and inspect.	

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM - Preflight Check-Out 156 INCH SPACE SHUTTLE MOTOR				Page 3 of 3	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
4. Inadvertent ignition				All igniters (Safe and Arm Devices) will be installed in the designated "safe" condition and not electrically connected until the "arm" command.	
				All ordnance items with the exception of the destruct initiators must be installed prior to liquid propellant loading. Electrical hooking of ordnance items will not be accomplished until after liquid propellant loading is complete.	
5. Unsafe Acts				NOTE: Environmental control max. 150°F.	
B. Installation of Airborne (A/B) Batteries				Class II	AFM 27-100 (Ordnance Safety) Bulletin 82a (Safety Inspection Survey Guide)
1. Insufficient charge				Batteries must be installed and connected prior to Space Shuttle liquid propellant loading.	
2. Bent or punctured battery case				Installation area must include the following safety items: Eye Darts Showers Necessary first aid equipment in areas where toxic materials are handled Lighting facilities must be adequate work platforms	
3. Damaged connectors or plugs					
4. Broken, cracked, or displaced cells					
5. Loose wire ends					

TABLE S-1 (Cont)
PRELIMINARY

OPERATING SAFETY ANALYSIS

OPERATION: SRM SEGMENT HANDLING AND TRANSPORTATION				Page 1 of 3	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Transport Segment to Railhead	*While there have been incidents of motors being dropped or in vehicle accidents involving truck rollovers and railway derailments, etc., no such incident has resulted in an ignition of the motor.	I. Damaging or Igniting Segment A. Vehicle Accident B. Excessive Shock Loading	IV	Transporter must have capacity to support load. Segment must be properly tied down. Transporter designed to absorb shock loads. Protective cover must be over segment. All operations to be accomplished using approved handling procedures. Segment to be grounded during shipment. Transporter must be properly safety equipped. a. Spark Arresters b. Fire Extinguishers c. Dangerous Placards d. No Hazardous Materials in Cab	*TCC Specifications *ASA B30.2 *ICC Shipping Regulations
Loading Segment on Railcar		II. Damaging or Igniting Segment	IV	All operations to be accomplished using approved handling procedures. P.W. required on all field lifting equipment, Facemask-Cutty harness and cranes. Minimum safety factor of three (3) required on all handling equipment. Use underslung rail car with hard points to interface with the support structure of the segment. Tie-down segment to rail car to support against longitudinal, lateral and vertical loads. Protective cover over segment.	

* Pertains to all Hazards/Undesirable Events (I through V)

* Pertains to all Hazards/Undesirable Events (I through VII)

TABLE 8-1 (Cont)

OPERATING SAFETY ANALYSIS

OPERATION: SRM SEGMENT HANDLING AND TRANSPORTATION					Page 2 of 3
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Transport SRM Segments to Assembly Site		III. Damaging or Igniting Segment A. Train Accident B. Excessive Shock Loading	IV	Height of SRM segment with protective cover in place not to exceed (TBD) feet. Empty railcar between each segment. Protective cover to remain in place during shipment. Railcar must have capacity to support load. Railcar shall have provisions for shock mitigation. Segment to be grounded during shipment. Shipment to be expedited and monitored throughout by TCC to prevent sidetracking or other anomalies.	
Transfer Segments from Railcar to Transporter		IV. Damaging or Igniting Segment	IV	All operations to be accomplished using approved handling procedures. Preventative Maintenance (PM) required on all load lifting equipment. Pneuma-Grip harness and cranes. Minimum safety factor of three (3) required on all handling equipment.	
Transport Segments to Rectifier, Inspect and Storage Area		V. Damaging or Igniting Segment A. Vehicle Accident B. Excessive Shock Loading	IV	Transporter must have capacity to support load. Segment must be properly tied down. Transporter designed to absorb shock loads. Protective cover must be over segment. All operations to be accomplished using approved handling procedures. Segment to be grounded during shipment. Transporter must be properly safety equipped. a. Spark Arresters b. Fire Extinguishers c. Dangerous Placards d. No Hazardous Materials in Cab	

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: SRM SEGMENT HANDLING AND TRANSPORTATION - Page 3					Page 3 of 3
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Handling Segments in Receive, Inspect and Storage Area		VI. Damaging or Igniting Segment	IV	All operations to be accomplished using approved handling procedures. PM required on all load lifting equipment, Pneuma-Grip harness and cranes. Minimum safety factor of three (3) required on all handling equipment. Support stands should be designed to withstand thrust if premature ignition should occur.	
Transport Segments to VAB.		VII. Damaging or Igniting Segment A. Vehicle Accident B. Excessive Shock Loading	IV	Transporter must have capacity to support load. Segment must be properly tied down. Transporter must be designed to absorb shock loads. Protective cover must be over segment. All operations to be accomplished using approved handling procedures. Segment to be grounded during shipment. Transporter must be properly safety equipped. a. Spark Arresters b. Fire Extinguishers c. Dangerous Placards d. No Hazardous Materials in Cab	

TABLE 8-1 (Cont)

OPERATING SAFETY ANALYSIS

PRELIMINARY

OPERATION: SRM FLIGHT 156 INCH SPACE SHUTTLE MOTOR		Page 1 of 6		
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS JUSTIFICATION
SRM - Ignition, Pressure Build-up, Lift Off and Down Range Flight	Based upon past experience, no case structural failures have occurred with D6AC material in Stage 1 Minuteman, and greater relative proof has been confirmed during pressure hydrotests.	1. Motor Case	Class IV	Vendor supplied technical case data (heat treat, metallurgical compliance, etc.) ASA B56.2 TCC Handling Manuals
		A. Failure to function as a pressure vessel		
		1. Defective metal		
		2. Damage during handling and transportation.		
		3. Excessive internal pressure/surface and increases	Class III	Quality and chemical laboratory analyses Visual inspection NDT requirements Temperature/humidity controls
		a. Propellant		
		1) Cracks		
		2) Voids		
		3) Slumping	Class III	Quality and chemical laboratory analyses Visual inspection NDT requirements Temperature humidity controls
		4) Separation		
		b. Insulation (internal)		
		1) Delamination		
		2) Voids	Class III	Maximum chamber pressure differential between the two SRM shall not exceed (TBD).
		B. Chamber Pressures		

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM FLIGHT 156 INCH SPACE SHUTTLE MOTOR		Page 2 of 6			
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
This possible event has never occurred with a production motor pyrogen.	II. Pyrogen (Main Motor)	A. Failure to ignite or sustain burning of SRM propellant	Class II	Control (Q. C.) of raw materials - shelf life, storage, distribution, etc.	TCC and NASA Specifications
		1. Defective materials and/or composition		Propellant shelf life determination	
This possible event has never occurred with a production motor pyrogen.	B. Case Failure	2. Deterioration of propellant and/or composition	Class III	NDT requirements Environmental controls	ASA B30.2 TCC and NASA Specifications
		3. Poor physical properties		NDT requirements	
		1. Propellant voids, separations, cracks, etc.		Visual inspections NDT requirements	
		2. Case bond discontinuities		Critical vendor Q. C. control	
		3. Insufficient material strength or thickness		Weight testing handling equipment (PAM), operator training	
		4. Rough handling		Supervision and directive on the job training	
		5. Human error			

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM FLIGHT 156 INCH SPACE SHUTTLE MOTOR		Page 3 of 6		
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS
<p>As prime contractor for the Minuteman Safe and Arm Device, Thiokol Chemical Corporation has access to the complete test records in which the S & A's are used. The aggregate tests for all models exceeds 2100 without a failure.</p> <p>Same as III.A.</p>		<p>III. Safe and Arm Device</p> <p>A. Failure to Arm or Safe</p> <ol style="list-style-type: none"> 1. Broken or corroded switches 2. Faulty Assembly 3. Defective or broken parts 4. Human error 	Class III	<p>Environmental control</p> <p>Certified operators and inspectors</p> <p>Visual inspections</p> <p>Electrical check-out</p> <p>Certified operators and inspectors</p> <p>TCC Specifications AFM 127-100</p>
		<p>B. Insufficient or No Energy Transmitted to Pyrogen</p> <ol style="list-style-type: none"> 1. Broken leads or bridgewire 2. Defective squib material 3. Failure to ignite one SRM 4. Human error 5. Squib deterioration 	Class III	<p>*Environmental control</p> <p>*Certified operators and inspectors</p> <p>*Visual inspections</p> <p>*Electrical check-out</p> <p>Abort</p> <p>* Pertains to all undesirable events</p> <p>TCC Specifications AFM 127-100</p>

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM Flight 156 INCH SPACE SHUTTLE MOTOR				Page 4 of 6	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Same as III.A.		C. Housing Fails to Withstand Internal Pressure During SRM Burn	Class II		TCC Specifications Process Instructions
		1. S&A housing to SRM case hot gas leakage			
		a. Faulty gasket		Stringent qualification tests and TCC parts acceptance criteria	
		b. Human error		Certified operators and inspectors	
		c. Internal insulation failure		Stringent qualification tests and TCC parts acceptance criteria	NOTE: S&A hold-down bolts must be torqued and safety wired for pressure retention of primary seal.
IV. Translation Separation Rockets					
As prime contractor for the Minuteman Safe and Arm Device, Thiokol Chemical Corporation has access to the complete test records in which the S & A's are used. The aggregate tests for all models exceeds 2100 without a failure.		A. Inadvertent ignition of S&A Device	Class III		TCC Specifications Process Instructions
		1. Electrical short between firing circuit and arming device		Stringent qualification tests Ensure that no possible channels exist that would cause a 400 voltage AC or DC short to the S&A electrical leads.	
		2. Human error		Certified installation and assembly operators.	
		3. Excessive temperature		Adequate insulations must envelope system to eliminate 400°F. temperature exposure.	

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM FLIGHT		156 INCH SPACE SHUTTLE MOTOR		Page 5 of 6	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Same as IV.A.		B. Failure to Perform Design Function			
		1. SLA device fails to arm and fire			
		a. Faulty assembly		Certified operators and inspectors	
		b. Broken or corroded switches		Environmental control	
		c. Defective or broken parts		Visual inspection	
		d. Human error		Certified operators and inspectors	
		2. Propellant fails to perform function			
		a. Low modulus		Controlled chemical laboratory analyses	
		b. Faulty raw materials		Controlled chemical laboratory analyses	
		c. Human error		Certified operators and qualified inspectors	
		3. Excessive internal pressure/surface increases	Class III		
		a. Propellant			
		1) Cracks		Quality and chemical laboratory analyses of products	
		2) Voids		NDT requirements	
		3) Slumping		Visual inspections	
		4) Separations			

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM FLIGHT		136 INCH SPACE SHUTTLE MOTOR		Page 6 of 6	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
		b. Insulation (internal) <ol style="list-style-type: none"> 1) Delaminations 2) Voids 3) Unbonded surfaces 4) Faulty materials 		Quality and chemical laboratory analyses of products NDI requirements Visual inspections	

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

Preliminary

OPERATION: VEHICLE ASSEMBLY BUILDING (VAB)		156 INCH SPACE SHUTTLE MOTOR	BASELINE SRM STAGE		Page 1 of 4
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
SRM Handling		I. Overhead Cranes			ASA B30.2 ICC Handling Manual ICC Safety Requirements
		A. Failures	Class IV		
		1. Faulty equipment a. Wire cables b. Clevises, hooks c. Monorails		Preventive Maintenance (PM) program - weight test all handling equipment bi-annually Visual equipment inspection	
		2. Operator error a. Accident b. Inadequate training c. Deviation		Proper training of operators by management Safety/employee program directed toward preventing accidents and certifying operators	
		3. Excessive load a. Operator error b. Ineffective color coding of cranes		PM program - weight test all handling equipment bi-annually Proper color coding of lifting and handling equipment	
		4. Mechanical failure a. Metal fatigue b. Rough handling c. Human error		PM program - weight test all handling equipment bi-annually NDT inspection of parts	
		5. Electric failure a. Electrical shorts b. Normal wear c. Human error		PM program - test all equipment bi-annually	
NOTE: All crane manual control units must have dead man switches.					

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OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont.)

OPERATION: Continuation of VAB 156 INCH SPACE SHUTTLE MOTOR		Page 2 of 4			
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
		B. Personnel	Class III		ASA B30.2 TCC Handling Manual TCC Safety Requirements
		1. Working beneath suspended loads		No one shall position themselves beneath a suspended load	
		2. Inadequately trained		Supervisor responsible for training and certifying personnel	
		3. Human error		Safety/employee program directed towards preventing accidents	
II. Handling Equipment (Spreader Bars, Wire Cables, etc.)					
		A. Failures	Class III		ASA B30.2 TCC Handling Manual TCC Safety Requirements
		1. Faulty Equipment		PM program - weight test all handling equipment bi-annually Visual equipment inspection	
		a. Metal fatigue			
		b. Frayed wire cables			
		c. Rough handling			
		2. Operator error		Proper training of operators by management/Safety.	
		a. Accidents			
		b. Inadequate training			
		3. Inadequate operator training		Proper training of operators by management/Safety.	
		4. Excessive loads		Proper color coding of lifting and handling equipment	
		a. Operator error			
		b. No maximum weight requirements		PM program - weight test all handling equipment bi-annually.	
		c. No color codes			

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of VAB 156 INCH SPACE SHUTTLE MOTOR			Page 3 of 4		
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
SRM Assembly	III. Hazards				
	A. Solvents (Flammables)		Class III		AFM 127-100 TCC Safety Regulations
	1. No personnel protective equipment			Solvent resistant gloves Respirators (as specified) Chemical monogoggles	
	2. Solvent not grounded			Solvents with flash points less than 140°F. must be grounded	
	3. No safety containers			Safety containers shall be used for all flammable liquids.	
	B. Handling SRM		Class III		AFM 127-101 ASA 330.2 TCC Safety Regulations
	1. Personnel working beneath suspended loads			No one shall work beneath a suspended load.	
	2. No personnel protective equipment			All operating personnel shall wear hard hats, safety shoes, coveralls, etc.	
	3. Improper color coding			All handling equipment must be weight tested and color coded to reflect current testing.	
	C. SRM Segment Mating		Class III		TCC Specifications NASA Standards AFM 121-100
	1. Misalignment			Dowel pins or equivalent	
2. Missing component parts (gaskets, bolts, etc.)			Visual inspections (O. C.) Check lists		

TABLE 8-1 (Cont)

OPERATING SAFETY ANALYSIS					Page 4 of 4	
OPERATION: Continuation of VAB 156 INCH SPACE SHUTTLE MOTOR						
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	MAJOR CLASS	SAFETY REQUIREMENTS	JUSTIFICATION	
		3. Defective components		Vendor certifications Receiving inspections Visual inspections		
		4. Excessive gaps B/W segments a. High internal pressure b. Excessive burning surfaces		Certified operators and inspectors Vendor controlled by Q. C. requirements		

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TABLE 8-1 (Cont)

OPERATING SAFETY ANALYSIS

Preliminary

OPERATION: SRM - HARDWARE RECOVERY		156 INCH SPACE SHUTTLE MOTOR		Part 1 of 5	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
Separation of SRM's from Space Shuttle Orbiter During Flight		<p>I. Separation</p> <p>A. Command Separation After Class III SRM's are Spent:</p> <ol style="list-style-type: none"> SRM device fails to respond on command Mechanical defects Electrical defects Faulty assembly Human error Insufficient D C voltage 		<p>Installation check-out tests</p> <p>Visual inspections</p> <p>Hermetically seal ignition systems</p> <p>Protective device must be utilized to eliminate</p> <p>Minimum D C voltage 12.5 to 14.0</p> <p>NOTE: Prior to SRM separation all live SRM devices will be cycled to the safe position.</p>	NASA Standards ICC Specifications

TABLE 8-1 (Cont)

OPERATING SAFETY ANALYSIS					Page 2 of 5
OPERATION: Continuation of SRM - Hardware Recovery		156 INCH SPACE SHUTTLE MOTOR			
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDERSIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
SRM - Recovery Operations/ Recovery Ship		IL Transporting SRM from Water to Ship Deck			ASA B30.2 TCC Handling Manual TCC Safety Requirements
		A. Lifting Crane	Class IV		
		1. Faulty equipment a. Wire cables b. Clevises		Preventive Maintenance (PM) program - weight test all handling equipment bi-annually Visual equipment inspection	
		2. Operator error a. Accident b. Inadequate training c. Deviations		Proper training of operators by management Safety/employee program directed toward preventing accidents Operator certification	
		3. Excessive load a. Operator error b. Ineffective color coding of cranes		PM program - weight test all handling equipment bi-annually Proper color coding of lifting and handling equipment	
		4. Mechanical failure a. Metal fatigue b. Rough handling c. Human error		PM program - weight test all handling equipment bi-annually NDT inspection of parts	
		5. Electric failure a. Electrical shorts b. Normal wear c. Human error		PM program - test all equipment bi-annually	
NOTE: All crane manual control units must have dead man switches.					

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM - Hardware Recovery 156 INCH SPACE SHUTTLE MOTOR				Page 3 of 5	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
		B. Personnel	Class III		ASA B30.2 TCC Handling Manual TCC Safety Requirements
		1. Working beneath suspended loads		No one shall position himself beneath a suspended load	
		2. Inadequately trained		Supervisor responsible for training personnel	
		3. Human error		Safety/employee program directed towards preventing accidents.	
		C. Handling Equipment (Sprea-Class IV der Bars, Wire Cables, etc.)			ASA B30.2 TCC Handling Manual TCC Safety Requirements
		1. Faulty Equipment		Preventive Maintenance program, weight test all handling equipment bi-annually.	
		a. Metal fatigue		Visual equipment inspection.	
		b. Frayed wire cables		Proper training of operators by management/Safety.	
		2. Operator error		Proper training of operators by management/Safety.	
		a. Accidents			
		b. Inadequate training			
		3. Inadequate operator training		Proper color coding of lifting and handling equipment.	
		4. Excessive loads		Proper color coding of lifting and handling equipment.	
		a. Operator error		Preventive Maintenance program, weight test all handling equipment bi-annually.	
		b. No maximum weight requirements			
		c. No color codes			
		5. SRM		Qualified handling equipment/ operators	
		a. Case wet & slippery		Handling equipment (pneumagrip, etc.) must be PAV'd and physically inspected prior to utilization.	
		b. Case charred, causing irregular O.D. surface			

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM - Hardware Recovery 156 INCH SPACE SHUTTLE MOTOR				Page 4 of 5		
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION	
Removal of Explosive Devices After SRM is Located on Ship		III. Ordnance & Hazardous Devices			NASA Standards TCC Specifications DOT (Department of Transportation) Specifications	
		A. Safe & Arm Devices	Class III			
		1. S&A's failed to safe on command prior to separation sequence			Only qualified operators will remove defective ordnance devices. Manually cycle S&A to the safe position before disassembling.	
		2. Inexperienced disarming crews			Certify operators	
		3. Damaged a. Internal b. External c. No procedures for disarming			All ordnance devices will be carefully removed and rendered safe; then packaged for handling in accordance with DOT requirements. All hazardous operations must have engineering/safety approved procedures.	
		B. Liner Shape Charge (LSC)	Class IV			TCC Specifications NASA Standards
		1. Damaged			Only experienced ordnance personnel will be allowed to remove or handle explosive ordnances.	
		2. Inexperienced Disarming Crew			Certify operators.	
		3. SRM a. SRM rolls over on LSC igniting it b. Not secured to ship deck			SRM shall be supported on two chocks. SRM shall be fastened securely to the ship deck.	

OPERATING SAFETY ANALYSIS

TABLE 8-1 (Cont)

OPERATION: Continuation of SRM - Hardware Recovery		156 INCH SPACE SHUTTLE MOTOR		Page 5 of 5	
TASK DESCRIPTION	CRITERIA/FACTS	HAZARDS/UNDESIRABLE EVENT	HAZARD CLASS	SAFETY REQUIREMENTS	JUSTIFICATION
	C. Batteries		Class II		
	1. Broken cases			Salvaged by certified personnel	
	2. Acid contaminated surfaces			Clean contaminated surfaces with water	
	3. Acid/eye, acid/skin contact			Eye baths and showers must be available on deck.	

7. Justification--Supporting justification for the requirements, such as data calculations, standards, specifications, federal and state laws and codes, etc.

As indicated in the System Safety Program Plan, tradeoff studies will be conducted to evaluate the safety aspects of configurations and operational modes. The only malfunction warning device requirement identified thus far is the differential chamber pressure indicator for the parallel burn configuration. The basis for this device is described in the manrating section. The orbiter turning rate sensors also provide intelligence on the extremely time critical attitude rate change resulting from thrust differences or thrust vector malfunctions.

A gross hazard analysis thus far indicates that launch under environmental conditions acceptable from purely operational considerations presents no unacceptable hazard. The analysis is based on the baseline 156 in. SRM stage and the add-on variations for parallel burn. Most of the technology to be utilized has been demonstrated on previous programs. Therefore, only the hazards associated with the as yet unproven factors require major attention. One major difference is that the system is manrated and of necessity will require increased safety factors, added Quality Assurance, added testing and design redundancy on critical electrical, hydraulic and ordnance systems.

8.1 ENVIRONMENTAL CONSIDERATIONS

In the parallel mode, two 156 in. diameter SRM's are mounted symmetrically on the side of the orbiter propellant tank. The booster motors and orbiter engines fire simultaneously. Each SRM contains 1.2 million lb of solid propellant whose exhaust products contain CO, CO₂, HCl, H₂O, H₂ and N in gaseous form, and Al₂O₃ in solid form.

Thiokol contracted with GCA Corporation to define the environmental effects of the SRM exhaust gases. Bolt Beranek and Newman, Inc, were also contracted to perform acoustic analyses of the farfield noise generated by the combined shuttle motors. Both companies are recognized experts in their fields. The study results from each company indicate that the environmental effects from launch or abort, in weather acceptable for launching, present no hazard. For the meteorological regimes considered and using the NASA developed models, ground level and stabilized cloud concentrations are well below maximum allowable levels. All farfield acoustic levels are well within acceptable endurance limits. The noise generated by the Space Shuttle is no worse than that of other large rocket motors.

The only possible environmental hazard posed by the rocket engine emissions is the tropospheric washout of HCl by precipitation and this phenomenon occurs only if the vehicle is either launched during rain showers or if such showers occur along the first 100 kilometers of the downwind trajectory of the elevated ground cloud of the exhaust products. If this trajectory is over water rather than land,

the harmful effects are minimized. For overland trajectories the possible harmful effects of acid rain on vegetation and other receptors should be carefully evaluated. Section 6.0 of this report contains a complete discussion of the environmental effects of the SRM use in the Space Shuttle program.

8.2 PROPELLANTS

The reliability of both propellants that will be used in the SRM have been proven in long term production missiles. The SRM Pyrogen igniter propellant is TP-H1016 which is currently used in the Minuteman Stage I Pyrogen igniter. The translation separation rocket propellant, TP-H1076, is used in the Genie motor. The SRM case propellant, TP-H1011, is used in the First Stage Minuteman motor. During the past 14 years, several thousand of these motors have been built, stored, transported and tested. None of the propellants cited have ever failed to perform nor have they ever ignited prematurely in the loaded motor configuration. These propellants are probably as well developed, tested, and proven as any in the solid propellant industry. The military classification for these propellants is Class II (Fire Hazard) and the Department of Transportation classifies them as Type B.

8.3 EXPLOSIVE DEVICES

Thrust termination of the SRM's will be used in the abort mode. By opening up vent ports in the head end of the SRM, its forward thrust can be immediately terminated. This is accomplished by a signal to a safe and arm device which in turn ignites dual electro-explosive devices (EED), a mild detonating cord and finally a linear shaped charge (LSC). The EED, detonating cord and LSC are all Class 7 explosives and must be handled with extreme care. Thiokol's experience with a similar thrust termination (TT) system on Third Stage Minuteman provides a good background in this area. Extensive reliability testing has been accomplished on this TT system and it has performed without failure in over 650 tests.

To assure ignition, the TT system will be provided with redundant initiators and electrical systems.

In the event that a destruct system is used for the SRM it would also use the ordnance items utilized in the TT system. The major difference being that the LSC would be installed down the entire length of the case in each raceway.

8.4 ISOLATION OF ENERGY SOURCES

The three energy sources that must be electrically and pyrotechnically isolated on the SRM are: (1) propellant (Pyrogen igniter, translation separation rocket and SRM grain), (2) TT system, and (3) destruct system, if used.

All of the above energy sources are isolated using the Thiokol developed S & A device. The S & A device provides and maintains an ignition safe attitude on either

mechanical or electrical command. Upon electrical command to the arm and thence to the fire position, it transmits pyrotechnic energy to the energy source.

During the past decade, this S & A device has been used with complete success on all three stages of the Minuteman missile, as well as Poseidon and other missile systems. To this date, the S & A device has never failed to fire on command or failed by firing when not commanded.

In addition to the energy sources described above, the various electrical distribution systems controlling ordnance and guidance systems on the missile must be isolated. This will be accomplished through proper design, inspection, and testing.

8.5 COMPATIBILITY OF MATERIALS

All materials utilized in fabrication of the SRM's are compatible. These same materials have been used for many years in the Minuteman and Genie programs, both long term production missiles.

8.6 EFFECTS OF TRANSIENT CURRENT AND RADIO FREQUENCY ENERGY

All electrical systems will be designed with the necessary shielding features to protect against any transient current and RF energy. The S & A device that will be used on all ordnance items has undergone extensive testing in this regard.

9.0 GROUND SUPPORT
EQUIPMENT

9.0 GROUND SUPPORT EQUIPMENT (GSE)

9.1 INTRODUCTION

Thiokol Chemical Corporation will provide the necessary personnel, facilities, and equipment to conduct a complete Ground Support Equipment (GSE) program in support of the SRM Stage. GSE definition, design, fabrication, verification, use and maintenance will be included as a part of this program. An initial effort has been conducted to identify items of GSE required to support the SRM Stage, with prime effort directed toward the 156-in. diameter SRM parallel burn configuration. The baseline 156-in. diameter SRM Stage parallel burn configuration consists of two SRM's, each with a case of three center segments, a forward and aft closure, fixed nozzle, igniter, aft skirt extension, nose cone, safe and arm device, raceway and associated cabling. In addition to the two SRM's the SRM Stage includes an interstage structure which provides the interface between the SRM Stage and the Space Shuttle. Alternate configurations to the 156-in. diameter parallel burn baseline include the following subsystems.

1. Thrust Termination
2. Thrust Vector Control (TVC)
3. Malfunction Detection System (MDS)
4. Flight Instrumentation System
5. Separation Motors
6. Destruct System
7. Recovery System

These additions to the baseline have been considered separately and the required GSE has been defined to support these subsystems.

Secondary to this effort, definition of GSE needed to support a 156-in. diameter SRM series configuration, an SRM Stage consisting of parallel 120-in. diameter SRM's and an SRM Stage using a 260-in. diameter series SRM was considered. A Systems Requirements Analysis (SRA) was used as the tool to identify GSE configuration items, design requirements and quantities required to support the SRM Stage. Use of the SRA has provided an orderly development of the GSE requirements.

Transportation and handling of the various components of the SRM Stage requires special equipment, due to the size and shape of some of the components. The modes of transportation considered for handling the large case segments included air, railroad and highway. For the 260-in. diameter SRM, water transportation was studied.

Tradeoff studies indicate that rail transportation of the 156-in. diameter SRM segments is the most feasible method to move the segments from the Thiokol/Wasatch Division facilities to the Kennedy Space Center (KSC). A minimum of GSE will be needed for this mode of transportation. Studies indicate there is no requirement for temperature conditioning or humidity control during transport. The existing railroad at the KSC will be used for transportation at the launch site. Overhead cranes with lifting capabilities of 200 tons will be provided at the various points of on and off loading of the railcars. A pneumatic handling harness was selected to interface with the SRM segments and the 200-ton cranes to provide a combination which will handle the SRM segments in the fastest, most economical way.

All components coming from vendors directly to the KSC will be packaged for shipment by the vendor and shipped via common carrier. The components coming from the vendor and those from the Thiokol/Wasatch Division will be assembled to the maximum extent possible, considering transportation limitations, to keep assembly at the KSC to a minimum. Subassembly of the SRM components at the KSC will be accomplished at a new Receiving, Inspection, Storage, Subassembly (RISS) building to be constructed near the Vehicle Assembly Building (VAB). These components will be assembled to the maximum extent possible, considering equipment checkout requirements, inspection requirements, transportation handling and SRM assembly requirements, and cost considerations, before transportation to the VAB.

Assembly of the SRM Stage in the VAB will be accomplished in a minimum time using a minimum quantity of GSE considering the following factors.

1. Safety
2. Human Engineering
3. Reliability
4. Available Facilities
5. Manpower
6. Launch Rate
7. Cost
8. Maintenance

Quick connect/disconnect philosophy has been used throughout for operations performed in the VAB. Handling, assembly and checkout requirements have been kept to a minimum.

Special test and checkout equipment will be used to perform tests required to insure reliability of the various SRM components. Equipment tests and checkouts will be performed on the SRM Stage in the RISS building on all assembled

components to minimize checkout in the VAB. An SRM Stage system test is to be conducted after SRM buildup in the VAB to verify the SRM Stage system prior to integration with the Space Shuttle. After Space Shuttle integration, combined systems tests will be performed to verify SRM Stage/Space Shuttle interfaces. Only those items of special test and checkout equipment directly required by the SRM Stage have been identified.

9.2 GROUND SUPPORT EQUIPMENT (GSE) DESIGN CRITERIA

9.2.1 Design Requirements

9.2.1.1 Design of the SRM Stage

The design of the SRM Stage establishes the design requirements for the GSE. Such things as component size, weight, configuration, etc, have to be considered in the GSE designs. The following SRM Stage description was used as the basis for GSE preliminary definition.

The SRM Stage is composed of two Solid Rocket Motors (SRM). Each SRM in the 156 in. diameter parallel configuration is composed of three center segments, one forward segment, one aft segment, interstage structure, aft skirt extension and nose cone.

The segments are all 156 in. diameter, vary in length from 21 to 27 ft and in weight from 166,000 to 325,000 lb.

The aft skirt extension is approximately 160 in. maximum diameter by 132 in. long and weighs approximately 12,000 lb. The aft skirt extension supports the weight of the SRM and one-half the weight of the Space Shuttle vehicle while on the launch pad. The aft skirt extension will be installed on the aft segment in the RISS building prior to SRM buildup.

The nose cone is conical, with a major diameter of 156 in., a length of 214 in., and a weight of 10,000 lb. The nose cone will be installed on the forward segment in the RISS building.

The interstage structure is composed of two major subassemblies, the forward attach structure and the aft attach structure. The forward attach structure is approximately 200 in. long and weighs approximately 4,700 lb. The aft attach structure is approximately 100 in. long and weighs approximately 500 lb. The interstage structure will be installed on the forward segment subassembly and the aft segment subassembly in the RISS building.

9.2.1.2 Experience

The manufacture and static testing of the large solid propellant rocket motors require that GSE be developed to handle, transport, assemble, checkout and

test the various SRM configurations. Thiokol's experience in the 156 in. diameter programs has been used in the identification of GSE required to support the SRM Stage in the Space Shuttle Program.

The feasibility of large solid propellant rocket motors - 100 through 260 in. diameter - has been demonstrated in a series of demonstration programs funded by the Air Force and National Aeronautics and Space Administration. Successful static tests of motors incorporating technology advancements were conducted by Thiokol Chemical Corporation, Lockheed Propulsion Company, Aerojet-General Corporation, and United Technology Center between 1964 and 1968. Further effort, especially directed at lowering costs of components, demonstrating new nozzles, and improving case and nozzle fabrication techniques, has been completed in the years since that time.

A total of 10 motors was built and static tested to demonstrate 156 in. diameter motor technology.

Segmented 120 in. motors have been used as zero stage boosters for the Titan IIC vehicle since June 1965, when the first flight was launched. One of the most successful of all space programs, the Titan IIC, was launched 17 times without a failure in the R & D phase.

The Titan IIC, part of the program managed by the Air Force Systems Command's then Space Systems Division (SAMSO), is the standard military heavy duty launch vehicle. It consists of a three stage common core vehicle with two five-segment solid propellant booster motors as the zero stage. The solid boosters have a combined liftoff thrust of 2.4 million lb.

Work also was accomplished under the Titan III/M (MOL) Program toward qualification of the seven-segment configuration of 120 in. motors.

Three 260 in. motors have been demonstrated by Aerojet-General Corporation. All used fixed nozzles, none with TVC, and all were ignited from the aft end.

Transportation of the 156 in. diameter SRM's has been demonstrated in both highway and rail transport modes. Mockups of 156 in. diameter segments have been transported by rail to various points throughout the country. The segments were supported in chocks and tiedowns in the same manner proposed for transporting the Space Shuttle SRM's.

The 156 in. diameter segments have been handled with Pneuma-Grip handling devices by Lockheed Propulsion Company. The 120 in. diameter segments have been handled by Pneuma-Grip handling devices in the Titan Program.

Techniques used by Thiokol in the assembly of the 156 in. feasibility motors have been used to advantage in the identification of equipment and personnel requirements in the Space Shuttle Program.

9.2.1.3 Design Criteria

A preliminary Systems Requirements Analysis was conducted to identify the design requirements for GSE in accordance with the procedures of AFSCM 375-5, "Systems Engineering Management Procedures" for expedience in preparation. It is recognized that future contracts may require use of NASA documentation.

The analysis identifies, to the maximum extent possible, the most practical and economic combination of GSE, facilities, personnel and technical data that best satisfy the system and design requirements. Where various solutions were available to solve a design requirement, tradeoff studies were conducted, within the scope of the contract, or previous experience was used to insure that the most practical solution was utilized to satisfy all requirements. The analytical approach emphasizes the philosophy of a minimal quantity of GSE to accomplish multiple tasks.

GSE, as presented in this study, was designed to satisfy all the requirements of the Operational Systems Analysis contained in Volume II, Appendix A, of this report.

In addition, the analysis has established a basis for a preliminary summary of facilities, manpower quantities and skills, and procedural data required to support the SRM Stage from manufacture through recovery.

9.2.1.4 GSE Design Criteria

The design parameters are predicated on fulfilling the system requirements at the lowest system cost without sacrificing safety considerations. Equipment design parameters in each major GSE category are presented in the following paragraphs.

The general approach to GSE design was to follow the experience gained in previous Thiokol conducted USAF and NASA funded large rocket motor programs. No design improvements or "convenience" design changes have been considered.

Transportation Equipment

Transportation equipment was selected on the following basis:

1. Rail transport will be the primary mode of transportation from Thiokol to KSC. Clearance has been made for shipment of segments in accordance with Figure 9-1 from Thiokol to KSC.
2. Highway transportation will be used for movement from Thiokol's Wasatch facility to the railhead and for movement within KSC from the RISS building to the VAB. The roadway from the RISS building to VAB at KSC will be designed to withstand the weight of the transporter loaded with a 325,000 lb segment. The total weight of segment and transporter will be approximately 400,000 lb.

All transportation equipment will be designed in accordance with MIL-M-8090 and AFSCM 80-6 or appropriate NASA specifications as applicable.

Handling and Assembly Equipment

Handling equipment will be required for all phases of SRM Stage transportation and assembly. Assembly equipment will be required at the RISS building and at the VAB.

All handling and assembly equipment will be designed in accordance with appropriate configuration item specifications. All lifting equipment will be designed to a load factor of three based on ultimate and shall be load tested to 1.5 times the expected operating load.

Test and Checkout Equipment

Test and checkout equipment will be used to test the various ordnance items, charge and test the batteries, perform continuity tests on all cabling and perform a final electrical system checkout when the SRM Stage is fully assembled.

Design of the test equipment will be in accordance with applicable NASA specifications. Special consideration will be given to environmental conditions which the equipment will see and electromagnetic interference (EMI) both from radiation and susceptibility standpoints.

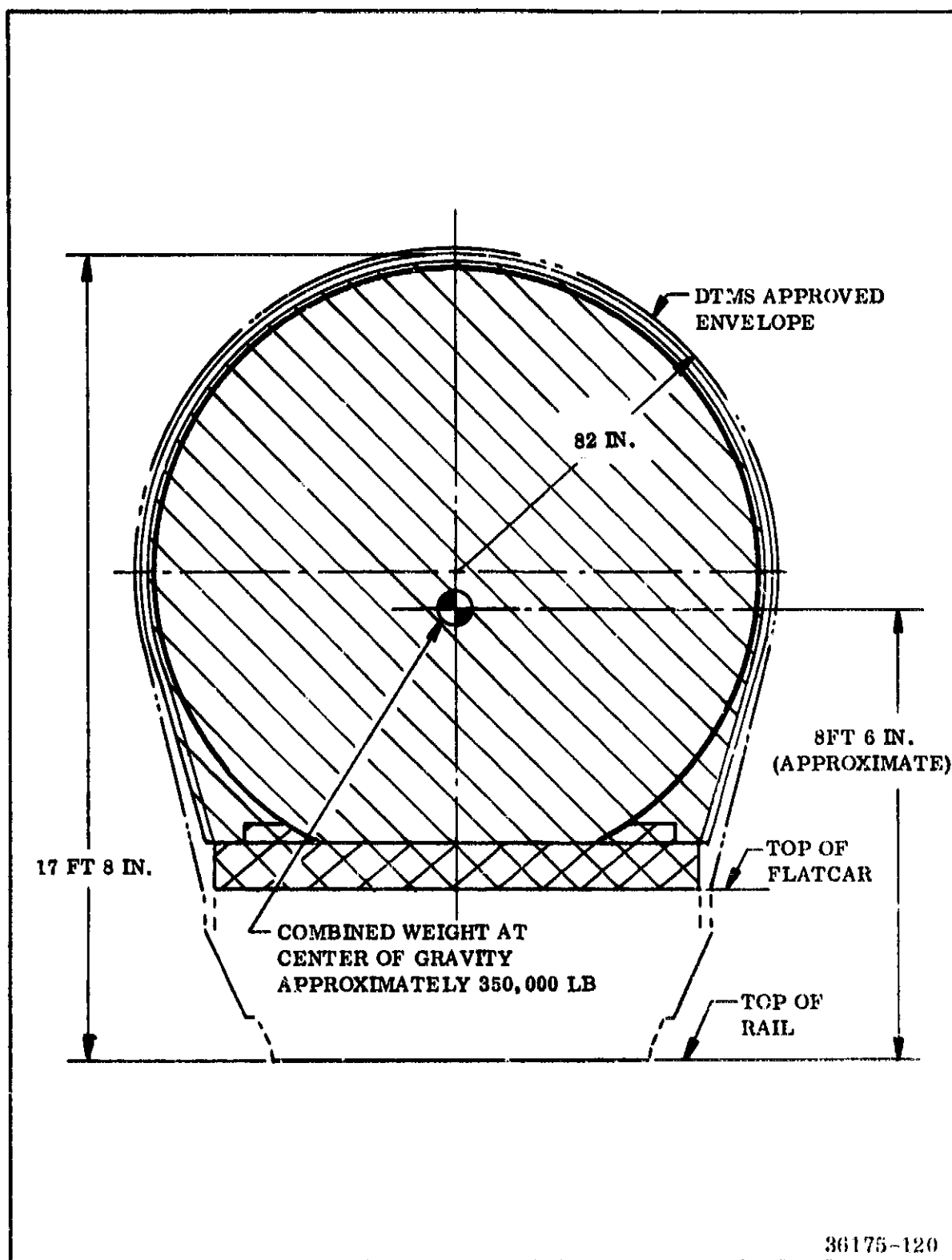


Figure 9-1. DTMS Envelope Limits

Design Verification

Verification tests will be performed in accordance with 6.2 of the General Test Plan for the Solid Rocket Motor (SRM) Stage contained in Volume III of this report. These tests will include verification of the test and checkout equipment, proof load tests on all lifting and handling equipment, and demonstration tests on all equipment.

9.2.1.5 Special Considerations

The following special considerations will apply to the design of each item of GSE.

Maintainability

Maintainability will be considered in the design of each item of GSE in accordance with the requirements of MIL-STD-470 or applicable NASA specifications as required.

Maintainability of GSE will be insured through the implementation of an effective maintainability program. The maintainability program will contain but not be limited to the following.

1. Maintainability program plan
2. Maintenance analysis of applicable items of GSE
3. Inputs to the detailed maintenance concepts and detailed maintenance plan
4. Establishment of maintainability design criteria
5. Performance of design tradeoffs
6. Prediction of maintainability parameter values
7. Incorporation and enforcement of maintainability requirements in design specifications
8. Participation in design reviews
9. Establishment of a data collection, analysis and corrective action system
10. Demonstration of the achievement of maintainability requirements in accordance with MIL-STD-471, as required
11. Preparation of maintainability status reports

Human Engineering Criteria

The design of each item of GSE will be considered in accordance with MIL-H-46855 or appropriate NASA specifications for impact on human engineering requirements. Human engineering will include the following.

Equipment Detail Design

During the detail design of equipment, the human engineering inputs, made in compliance with the system engineering analysis requirements as well as other appropriate human engineering inputs, will be converted into detail equipment design features. Design of the equipment will meet the applicable criteria of MIL-STD-472 or other human engineering criteria specified by the contract. Human engineering personnel shall participate in design reviews of equipment end items to be operated or maintained by man.

Human engineering principles and criteria will be applied, during detail design, to equipment drawings, such as panel layout drawings, overall layout drawings, controls and other drawings depicting equipment important to system operation and maintenance by human operators, to assure that the equipment can be efficiently, reliably, and safely operated and maintained.

9.2.2 Major Assumptions

With the limited data available the following basic assumptions were made on which the operational analysis is based.

1. The integrated Space Shuttle system orbiter, or ground power will furnish all required excitation and stimuli to perform a complete functional check of the TVC system after SRM Space Shuttle integration if a TVC system is used.
2. Ordnance unit checkout after Space Shuttle vehicle integration will be limited to monitoring to assure safe or arm condition and connector mating integrity.
3. Ordnance safe and arm devices will not be installed until after the SRM Stage/Space Shuttle combined system tests. Simulators will be used to this point.
4. Checkout of the SRM before integration with the Space Shuttle will be accomplished to the maximum extent possible to preclude a teardown due to anomalies found during SRM Stage/Space Shuttle combined system tests.
5. A low pressure test of the assembled SRM will be required to check for leaks in the various joints.

6. The support base on which the SRM Stage is assembled will have capability for SRM vertical alignment.
7. The support base will be provided by NASA.
8. Maximum assembly of SRM Stage components will be accomplished prior to transfer to the Vertical Assembly Building (VAB) for SRM buildup, so far as practical.
9. The VAB will be used for assembly of the Space Shuttle vehicle.
10. All components coming from vendors directly to KSC will be packaged for shipment by the vendor and shipped via common carrier.
11. A railroad extension will be provided from the existing railroad to a building (RISS building) to be built near the Space Shuttle Vehicle Assembly Building.
12. A roadway which will handle approximately 400,000 lb loads will be built from the new RISS building to the Space Shuttle Vehicle Assembly Building.
13. Thrust termination, command destruct, TVC, stage separation rockets, and recovery capability may be required.
14. On pad maintenance will consist of removal and installation of modules or subassemblies.
15. Preventive and corrective maintenance will be performed at the launch site on all items of GSE.
16. Crane services during SRM buildup will be provided by NASA.
17. SRM Stage buildup during GTM and FTM operations will require a minimum of nine days.
18. SRM Stage buildup during production operations will be accomplished in three days.

19. Thiokol's responsibility for the SRM Stage ends upon completion of SRM Stage assembly prior to integrating the Space Shuttle to the SRM Stage. However, Thiokol will be responsible for that portion of the final test and checkout that pertains to the SRM Stage.
20. Transportation of SRM segments from Thiokol's Wasatch Division to KSC will be by highway and rail. Size and weight limitations (see Figure 9-2) restrict transportation to the limited highway and rail modes.

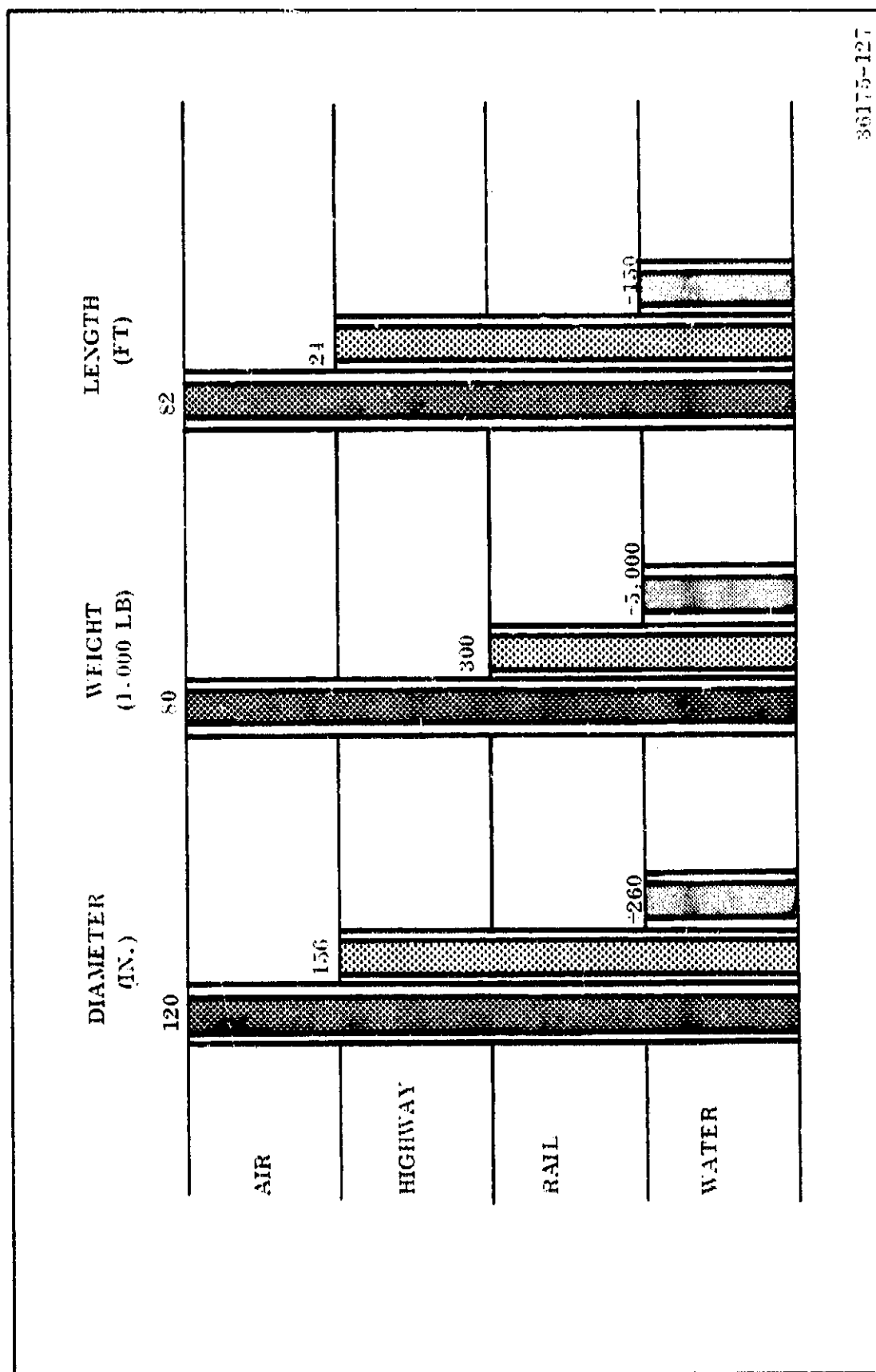
It is recognized that complete substantiation or corrections to the assumptions can only occur following further system definition and indepth tradeoff studies. The SRA documentation used for the GSE definition (Volume II, Appendix A) includes:

Functional Flow Diagrams (FFD's)

FFD's developed include top level FFD's with subflows to the level required to properly define a reasonable development of design requirements and criteria.

System Functional Analysis

Requirement Allocation Sheets (RAS's) were used to document the detailed analysis. These sheets were prepared for each block of the FFD's involving SRM Stage equipment and associated GSE design constraints. The RAS's identify design requirements for the SRM Stage ground support equipment.



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Figure 9-2. Transportation Limitations

9.3 SELECTION OF GROUND SUPPORT EQUIPMENT

9.3.1 GSE Selection Criteria

Using the System Requirements Analysis (SRA) and Military Standards and Specifications identified above, GSE was selected to support and perform all operations required from the transportation of SRM segments and components from the point of manufacture to the final test and checkout of the assembled SRM Stage. Experience gained in USAF and NASA 156 in. and 120 in. diameter SRM feasibility programs was a great asset in selecting the various items of GSE required to support the Space Shuttle Program.

The SRA identified the requirements to perform each operation. Equipment was then identified to fulfill the requirements. Consideration was given to past experience in the selection of transportation and handling equipment. Size and weight restrictions limited the transportation modes of the various configurations in accordance with Figure 2.

With primary consideration given to the 156 in. diameter segmented motor, rail transportation was selected as most feasible and economical. Transportation of 120 in. diameter segments by air or highway is feasible but more economic by rail. Transportation by water is the only feasible method of moving 260 in. diameter SRM's.

A Pneuma-Grip handling device was selected to handle the SRM's segments during transfer and assembly operations for ease of operation and to minimize equipment costs.

Test and checkout equipment was chosen based on performance of similar functions performed in other solid propellant programs such as the USAF Minuteman and 156 in. and 120 in. diameter feasibility studies.

9.3.2 GSE Description (Baseline SRM)

The following items of GSE have been identified to fulfill the requirements identified in the SRA.

Electrical Leads

Electrical leads or grounding straps will be used in all handling and transporting functions to insure safety by the prevention of electrical charge buildup on the SRM segments.

Case Stiffeners

Case stiffeners are structural members that fasten to the joints of the open ends of each segment. Case stiffeners will be installed on the joints of each segment after the segment has been rounded and propellant cast. The stiffeners will support the joint in its round condition throughout all transportation and handling functions. The stiffeners will only be removed when the segment has been broken over to a vertical position and is ready for assembly.

Tractor

The tractor is a special heavy duty prime mover with a fifth wheel connector. The tractor will provide power to pull the semitrailer with the SRM segments aboard.

Safety and Arming Device Simulator

Safety and arming simulators are devices having all of the electronic functions of the live S & A devices but lacking the explosive charges. The S & A simulators are used in the functional checkout of the SRM Stage to insure electrical continuity and allow checkout of the SRM electrical parameters.

SRM Leak Test Set

The leak test set is used to insure integrity of the joints and component interfaces when the SRM has been fully assembled. The test set consists of a seal installed in the nozzle throat. Various connections and lines will be installed in the seal to pressurize and vent the SRM, as required. A console will be provided to register and monitor the pressure.

Work Platforms

Work platforms are stairs and catwalks that provide access to the various work stations on the SRM segments and equipment. Work platforms will be required in the RISS building to provide access for inspection and subassembly operations. Work platforms will also be required in the VAB for segment breakover.

Semitrailer

The semitrailer is a special heavy duty trailer with tiedown and support provisions for supporting the SRM segments during transportation. The semitrailer will be used to transport the segments from Thiokol/Wasatch manufacturing area to the railhead and from the RISS building to the VAB at KSC.

O-Ring Fabrication Tool

The O-ring fabrication tool cuts O-ring stock material to specified dimension and secures the cut ends while the sealant cures. O-rings will be fabricated at KSC for the joint seals.

Ordnance Test Set

The ordnance test set consists of electronic components, gages and wiring housed in a console. All components are standard off-the-shelf items of modular design to the greatest extent possible. The ordnance test set will be used to completely test all ordnance units and associated cabling used on the SRM Stage. This will include cycling time, squib and motor resistance, continuity resistance and hi-pot leakage resistance. Test currents will be fail-safe limited to prevent inadvertent firing of electro-explosive devices.

Pneuma-Grip Lifting Device

The Pneuma-Grip lifting device is a specially designed device that is placed around the SRM segment and contains bladders which will be inflated to 50 psi. The pressure of the bladder on the segment case is sufficient to support the segment during all handling and assembly operations.

Breakover Stand

The breakover stand consists of structural supports that interface with the trunnions on the lifting device. The stand also contains stairs and platforms that provide access to the work areas on the stand and on the segment. The breakover stand is used to support the SRM segment while breaking the segment over from the horizontal to the vertical position using an overhead crane and lifting device.

Shipping Containers, S & A Devices

The shipping container is a standard AN reusable shipping container with special packing to support and protect the S & A device. The containers will be used to ship the S & A devices from their point of manufacture to their installation point.

Storage Chocks

Storage chocks are structural members that interface with the OD of the case near the joints or skirts. The chocks will support the segments while in storage.

Ladder, Nose Cone

The nose cone ladder is a special ladder that will fit in the nose cone to provide access to the forward dome of the forward segment to accomplish final assembly and checkout of components.

Protective Cover

The protective cover is a double layer of waterproof fabric with an internal layer of insulation. The protective covers are used during transportation to protect the segment from direct sunlight and inclement weather.

Tiedowns and Support Chocks, Rail

The rail support chocks are structural members that interface with the OD of the segment case near the joints and skirts. The tiedowns are flexible steel straps that attach to the chocks and fit over the segments. The tiedowns and chocks support and restrain the segment during rail transport.

Tiedowns and Support Chocks, Trailer

The trailer chocks and tiedowns are identical to those used on the railcar, except that they interface with the trailer.

Battery Charger and Test Set

The batteries used on the SRM Stage must be charged just prior to installation in the SRM. The charger and test set will be fabricated from commercial components. The charger will charge the batteries and check the charge level.

Lifting Adapter - Nose Cone

The nose cone lifting adapter is a structural member that attaches to the nose cone and provides attach points and structural support for the nose cone. The adapter is used in conjunction with the lifting adapter and overhead crane.

Lifting Sling - Nose Cone

The nose cone lifting sling is a special unit that adapts the lifting adapter to the overhead crane. The sling is used to support the nose cone while moving it with the overhead crane.

Lifting Beam - Loaded Segment

The lifting beam is a structural member that interfaces with the lifting device and the overhead crane. The lifting beam is used during the segment handling and assembly functions.

Electrical Cable Test Set

The electrical cable test set consists of standard electronic components, gages and wiring housed in a console. The test set is used to perform end-to-end continuity checks.

Dummy Storage Batteries

Dummy storage batteries consist of standard commercial components that enable the simulation of the battery current during systems checkouts.

Electrical System Checkout Set

The electrical system checkout set consists of standard electronic components, gages and wiring housed in a console. The checkout set is used to perform final checkout of the various electrical components and systems in the assembled SRM.

9.3.3 GSE Description (156 In. Options)

The following items of GSE have been identified to fulfill the requirements of the various options identified in the SRA.

HPU/Nozzle Test Set

Checkout at VAB will be restricted to cold gas operation of the HPU and controls. This check will require both the actuation system checkout console and the pneumatic regulation unit defined herein. Checkout on the launch pad will consist of cold gas functional operation checks during the control system final verification. During the final periods of countdown prior to launch, a hot run on the HPU and control devices will be performed. The HPU has dual ignition capabilities and the initiator unit will be replaced after ground check. There are sufficient amounts of fuel for two (2) complete ignition cycles and operational needs of each HPU. The control system will be completely checked out with the use of the checkout console. Checkout tests will cover all the operating modes including abort and shutdown. The entire system will be operated in emergency conditions of partial shutdown of one unit and full shutdown of one unit.

The following components will be checked out.

TVC Actuator

A TVC servoactuator checkout console will be required for design verification testing and prelaunch checkout of the TVC actuators.

This console will provide the following TVC actuator functions.

1. Linear variable differential transformer (LVDT) excitations
2. LVDT demodulations
3. Pressure transducer excitations and conditionings
4. Feedback and command summing and compensation
5. Servoactuator drivers
6. Failure static indicators
7. Failure reset capability
8. Simulated voters and failure detectors

9. Instrumentation interface
10. Simulated failures of all critical signals
11. Emergency hydraulic system shutoff
12. Electrical power control to actuators and servos
13. Hydraulic power control to actuators and servos
14. All electrical power conversion required for the facility

The control console power will be 115 v 60 Hz single phase and the unit will use breadboard electronics throughout. Single external hydraulic power supply will provide the fluid power for checkout tests.

Hydraulic Power Unit Controls

A hydraulic power unit and checkout console will be required for testing and checkout. The console will provide the following functions:

1. 28 vdc power - bus A & B
2. Power unit on and off controls
3. Turbine speed and governing controls
4. Test points

The control console will be composed of breadboard electronics to simulate the flight electronics.

Pneumatic Regulation Unit

A pneumatic pressure regulating unit for intermittent operation of the turbine HPU will be required. The unit will provide gaseous nitrogen for controlling the turbine and operating various fuel control valves during assembly and preliminary checkout.

Nozzle Alignment Set

The nozzle alignment set consists of components that interface with the nozzle and enable the determination of the nozzle centerline. The alignment set is used to align the nozzle in accordance with the specification requirements.

Shipping Container, Staging Rockets

The staging rocket shipping containers are reusable, with special packing to support the staging rockets. The containers are used to transport the staging rockets from the point of manufacture to the point of installation.

Nozzle Shipping Link

The nozzle shipping link is a structural support that interfaces between the HPU and nozzle exit cone. The shipping link supports the nozzle exit cone while the aft segment is being transported.

Pin Puller

The pin puller is a tool that attaches to the pins and is used to extract them from the segment joints. This allows disassembly of the SRM cases for refurbishment.

Chocks - Empty Case

The empty case chocks are structural members that interface with the OD of the case. The chocks will support the expended SRM and segments while disassembling the SRM for refurbishment.

Lifting Device - Empty Case

The empty case lifting device is identical in design and function to the loaded case lifting device.

Lifting Sling

The lifting sling is a device that adapts the gantry crane to the lifting device. The sling is used in disassembly and handling the SRM segments during refurbishment.

Lifting Device-Nozzle

The nozzle lifting device is a structural framework that attaches to lifting points on the nozzle. The lifting device is used to handle the nozzle during refurbishment.

HPU Shipping Chocks and Cover

The HPU shipping chocks and cover is basically a container with special support structures to hold the HPU for shipment to the vendor for refurbishment.

Semitrailer - Empty Case

The semitrailer is basically the same as the semitrailer used for the loaded case.

Tractor

The tractor is a commercial fifth wheel type prime mover used to pull the empty case semitrailer.

Chocks and Tiedowns

The chocks and tiedowns are identical to those used in transporting the loaded segments.

9.3.4 GSE Description (Alternate Configurations)

9.3.4.1 156 In. Series Configuration

The GSE required to support the 156 in. series SRM is essentially the same as the 156 in. parallel SRM. Quantities of equipment will vary with increased production rates.

9.3.4.2 120 In. Parallel Configuration

The GSE required to support the 120 in. parallel burn is essentially the same as the 156 in. parallel burn. Quantities of equipment will vary with increased production rates.

9.3.4.3 260 In. Series Configuration

A preliminary analysis of the 260 in. series configuration indicates that the following configuration items of GSE and related facility items at KSC will be required.

Gantry Crane

A 2,000 ton gantry crane would be required to remove the SRM from the barge, break it over to a vertical position and place it on the transporter launcher. Cranes of this size are feasible but not developed.

Barge

Water is the only feasible method of transporting the 260 in. diameter SRM from the point of manufacture to the KSC. The barge will have special ballast

tanks to enable loading and unloading of the SRM. The barge will be of shallow draft design to enable operation on the inland waterway.

Breakover Stand

The breakover stand is a structural framework that will interface with the SRM lifting adapter. The breakover stand will be used in conjunction with the gantry crane and lifting beam to break the SRM over to a vertical position.

Lifting Adapter

The lifting adapter is a structural member with trunnions that will support the breakover weight of the SRM. The support adapter will support the SRM during transportation and breakover operation.

Canal System

A canal system will be required to enable the SRM to be brought as close as possible to the launch pad before being removed from the barge.

Rotating Pit

A rotating pit will be required to provide clearance for the nozzle when breaking the SRM over to a vertical position.

Gantry Crane Foundation

A foundation will be required to support the gantry crane between the dock area and the point where the SRM will be placed on the transporter launcher.

9.4 FACILITIES

The system requirements analysis has identified the need for new facilities at two locations, the railhead near Corinne, Utah, and a facility near the Vehicle Assembly Building (VAB) at the Kennedy Space Center.

9.4.1 Corinne

A building containing a 200 ton overhead crane must be provided at the railhead near Corinne. This building will provide shelter during loading of SRM segments on railcars. The building must have approximately 4,000 sq ft of floor space to allow for the side-by-side orientation of the semitrailer and railcar. Railroad tracks must enter and leave the building. The doors will allow entry and exit of both the railcar and semitrailer/tractor. A reinforced concrete pad will be provided to support the semitrailer during transfer operations.

9.4.2 KSC

A building will be provided at KSC to receive, inspect, subassemble and store SRM Stage components, GSE and spares. The building must contain a 200 ton gantry crane covering the full length of the building. In addition, 10 ton auxiliary hoists will be provided to handle small components. Storage racks will be provided for small component storage. Floors will be capable of supporting the weight of the SRM segments including shipping equipment. Forklift use capability will be designed into the building. The lighting required is 100 ft candles minimum at the working level in the inspection, subassembly and office areas. Other areas require 60 ft candles minimum. Offices and rest rooms will be provided. Total space required is estimated to be 30,000 sq ft. Temperature control will be required to maintain temperature at 70° to 80° F.

In addition to the building, a railroad spur must be provided from the existing railroad bed into the building.

Also a roadbed must be provided from the RISS building to the VAB for tractor/semitrailer transport of the SRM segments to the VAB. It is estimated for this study that the rail spur will be 0.5 mi long and the roadbed will be 0.5 mi long.

9.5 PROGRAM GSE REQUIREMENTS

9.5.1 156 In. Diameter Parallel Configuration

The GSE configuration items and quantities required to support the 156 in. diameter parallel baseline configurations are as shown in Table 9-1. The additional configuration items and quantities required to support the 156 in. diameter configuration with TVC and staging capabilities are shown in Table 9-2. The configuration items and quantities required to support the refurbishment option are shown in Table 9-3.

9.5.2 156 In. Diameter Series Configuration

The GSE configuration items required to support the 156 in. diameter series baseline configuration are as shown in Table 9-4. The additional configuration items and quantities required to support the 156 in. diameter configuration with TVC are shown in Table 9-5.

9.5.3 120 In. Diameter Parallel Configuration

The GSE configuration items required to support the 120 in. diameter parallel configuration are as shown in Table 9-6.

9.5.4 260 In. Diameter Series Configuration

The GSE configuration items required to support the 260 in. series configuration are shown in Table 9-7.

TABLE 9-1

**GROUND SUPPORT EQUIPMENT
156 IN. PARALLEL CONFIGURATION**

	<u>GTM or FTM</u>	<u>10/Yr</u>	<u>20/Yr</u>	<u>40/Yr</u>	<u>60/Yr</u>
1. Electrical Lead	30	30	45	105	120
2. Lifting Beam, Loaded Segment	3	3	3	3	4
3. Tractor	3	3	3	3	4
4. Ladder, Nose Cone	1	1	1	1	2
5. RM Leak Test Set	1	1	1	1	2
6. Work Platforms	1	1	1	1	2
7. Semitrailer	3	3	3	3	4
8. Shipping Container, S & A Device	12	12	18	42	48
9. Ordnance Test Set	1	1	1	1	2
10. Pneuma-Grip Lifting Device	3	3	3	3	4
11. Breakover Stand	1	1	1	1	1
12. O-Rings Fabrication Tool	1	1	1	1	1
13. Storage Chocks	20	20	40	80	100
14. Electrical System Checkout Rocket Motor	1	1	1	1	1
15. Protective Cover	25	25	35	75	85
16. Tiedowns and Support Chocks, Rail	25	25	25	65	75
17. Tiedowns and Support Chocks, Trailer	3	3	3	3	4
18. Battery Charger and Test Set	1	1	1	1	1
19. Lifting Adapter-Nose Fairing	1	1	1	1	2
20. Lifting Sling-Nose Fairing	1	1	1	1	2
21. Case Stiffeners	25	25	35	75	85
22. Electrical Cable Test Set	1	1	1	1	1
23. Dummy Storage Battery	4	4	6	14	16
24. Safety and Arming Device Simulator	12	12	18	42	48

TABLE 9-2
GROUND SUPPORT EQUIPMENT
156 IN. PARALLEL, TVC AND STAGING OPTIONS

	GTM or FTM	<u>10/Yr</u>	<u>20/Yr</u>	<u>40/Yr</u>	<u>60/Yr</u>
HPU/Nozzle Test Set	2	2	2	2	2
Nozzle Alignment Set	1	1	1	1	2
Shipping Container, Staging Rocket	16	16	32	64	80
Nozzle Shipping Link	6	6	8	16	20

TABLE 9-3

**GROUND SUPPORT EQUIPMENT
150 IN. PARALLEL REFURBISHMENT OPTION**

	<u>GTM or FTM</u>	<u>40/Yr</u>	<u>60/Yr</u>
Pin Puller	2	4	4
Chocks	20	20	20
Lifting Device, Empty Case	1	1	1
Bridge Crane	1	1	1
Lifting Sling	1	1	1
Lifting Device, Nozzle	1	1	1
Semitrailer		1	1
Tractor		1	1
Chocks and Tiedowns		1	1
Grit Blast Facility	1	1	1
Paint Sprayer	1	1	1
Degreaser	1	1	1
Forklift Truck	2	2	2
Work Platform	2	2	2
New Facility Building 10,000 sq ft			
Overhead Crane, 15 ton	1	1	1
HPU Shipping Chocks and Cover	2	8	12

TABLE 9-4
GROUND SUPPORT EQUIPMENT
156 IN. SERIES

	<u>GTM or FTM</u>	<u>GO/Yr</u>
1. Electrical Load	30	140
2. Lifting Beam, Loaded Segment	3	4
3. Tractor	3	4
4. Ladder, Nose Cone	1	2
5. RM Leak Test Set	1	2
6. Work Platforms	1	2
7. Semitrailer	3	4
8. Shipping Container, S & A Device	12	48
9. Ordnance Test Set	1	2
10. Pneuma-Grip Lifting Device	3	4
11. Breakover Stand	1	2
12. O-Ring Fabrication Tool	1	1
13. Storage Chocks	20	100
14. Electrical System Checkout Rocket Motor	1	2
15. Protective Cover	25	100
16. Tiedowns and Support Chocks, Rail	25	90
17. Tiedowns and Support Chocks, Trailer	3	4
18. Battery Charger and Test Set	1	2
19. Lifting Adapter-Nose Fairing	1	2
20. Lifting Sling-Nose Fairing	1	2
21. Case Stiffeners	25	85
22. Electrical Cable Test Set	1	2
23. Dummy Storage Battery	4	24
24. Safety and Arming Device Simulator	12	48

TABLE 9-5
GROUND SUPPORT EQUIPMENT
156 IN. TVC OPTION

	<u>GTM or FTM</u>	<u>10/Yr</u>	<u>20/Yr</u>	<u>40/Yr</u>	<u>60/Yr</u>
HPU/Nozzle Test Set	2	2	2	2	2
Nozzle Alignment Set	1	1	1	1	2
Nozzle Shipping Link	6	6	8	16	20

TABLE 9-6
GROUND SUPPORT EQUIPMENT
120 IN. PARALLEL

	<u>GTM or FTM</u>	<u>60/Yr</u>
1. Electrical Lead	60	240
2. Lifting Beam, Loaded Segment	6	8
3. Tractor	6	8
4. Ladder, Nose Cone	2	4
5. RM Leak Test Set	2	4
6. Work Platforms	2	4
7. Semitrailer	6	8
8. Shipping Container, S & A Device	24	96
9. Ordnance Test Set	2	4
10. Pneuma-Grip Lifting Device	6	8
11. Breakover Stand	2	2
12. O-Ring Fabrication Tool		1
13. Storage Chocks	40	200
14. Electrical System Checkout Rocket Motor	2	2
15. Protective Cover	50	170
16. Tiedowns and Support Chocks, Rail	50	150
17. Tiedowns and Support Chocks, Trailer	6	8
18. Battery Charger and Test Set	2	2
19. Lifting Adapter-Nose Fairing	2	4
20. Lifting Sling-Nose Fairing	2	4
21. Case Stiffeners	50	170
22. Electrical Cable Test Set	2	4
23. Dummy Storage Battery	8	32
24. Safety and Arming Device Simulator	24	96
25. HPU/Nozzle Test Set	2	4
26. Nozzle Alignment Set	2	4
27. Nozzle Shipping Links	12	40

TABLE 9-7
GROUND SUPPORT EQUIPMENT AND
RELATED FACILITIES, 260 IN. SERIES

	<u>GTM or FTM</u>	<u>GO/Yr</u>
1. Gantry Crane	1	1
2. Breakover Stand	1	1
3. Barge	TBD	TBD
4. Lifting Adapter	TBD	TBD
5. Canal System	1	1
6. Rotating Pit	1	1
7. Gantry Crane Foundation	1	1

9.6 MAINTENANCE AND SPARES

9.6.1 Maintenance

The GSE will be designed with ease of maintenance as a design consideration. The maintenance requirements will be coordinated with the maintainability program. These data will be incorporated as qualitative maintainability requirements to minimize complexity, design for minimum quantity of tools and test equipment, design for minimum skill levels for operation and maintenance and optimum accessibility. These criteria will be based upon knowledge gained in Thiokol's solid rocket motor programs, Minuteman, and advanced research programs on 120 in. and 156 in. diameter solid motors. The maintenance program defined in the Logistic Support Plan, Volume III, will provide effective maintenance support for the GSE. The maintenance program will enumerate all system support action required for retaining or restoring the GSE to an acceptable operating condition. This program will assure system readiness of the GSE and will preclude delay times due to GSE being unavailable or inoperable. During design of the equipment, Thiokol will, as contractually directed by NASA, prepare calibration, certification, and measuring standards to be utilized at the launch site. Based upon system engineering documentation, Thiokol will establish final quantity requirements for GSE with approval of NASA.

The basic philosophy for the site maintenance program is to conduct both scheduled and unscheduled maintenance for the ground support equipment. The scheduled maintenance program for the GSE will provide procedures for inspection, testing, servicing, calibration, and reconditioning the equipment at regular intervals. The objective of this preventive maintenance program is to prevent equipment failures in service, and to retard wearout deteriorations. During the design and verification program the maintenance engineering group will establish the periodic maintenance program for the ground equipment, based upon calendar or use time for each item. This periodic maintenance program for the launch site does not include overhaul. All overhaul activities associated with the GSE will be conducted at Thiokol or vendor facilities. Thiokol will establish the scheduled and unscheduled maintenance requirements for the GSE. The systems maintenance requirements will be developed utilizing NASA required documentation. These data will be summarized to identify and correlate frequency of maintenance occurrences and personnel, MGE, and spares provisioning. The compilation of calibration requirements will be integrated in the maintenance task analysis to define measuring and alignment standards.

The alignment and/or adjustment of the GSE installed at the launch site will be accomplished using portable calibration equipment when and wherever practical. GSE that must be removed, or that equipment which may require special calibration, will be transported to either the calibration laboratory at the launch site or an offsite calibration facility. Calibration requirements for the GSE will be kept to a minimum.

9.6.2 Spares

Spare parts requirements will be defined by Thiokol's maintenance analysis of the GSE. Based upon the approved quantities of equipment and maintenance loading, the selection and identification of spares quantities will be established. These spares quantities will be sufficient to support the integration and checkout during DDT & E and production for the SRM Stage.

The data derived from the maintenance analyses will support federal stock number screening requirements and the preparation of reports and applicable documentation for the provisioning of spare parts. Factors that Thiokol will consider in the identification and selection of spare parts and quantities for the GSE include, but are not limited to: installation status, maintenance function, maintenance limitations of the equipment, source code (manufactured or procured), shelf life, reparable or nonreparable characteristics, repair cycle time, wearout rates (percentage condemnation of reparable item), percentage of operating time, calibration frequency, inspection frequency, consumption data and reliability history (failure rates and reports, reliability factors), units/assembly/installation/total program usage, effectivity, need dates/program schedules, lead time, cost, and experience with like type equipment.

9.6.3 Support

Past experience has shown that the total costs to perform maintenance and provide the required spare parts for the maintenance functions approximates 12 percent/year of the cost of the GSE. Thiokol's goal will be to meet or reduce this figure by selective and careful GSE design. Past experience, as related above, has provided Thiokol with the tools and knowledge to accomplish this goal.

100 TRANS, ASSY &
CHECKOUT

10.0 TRANSPORTATION, ASSEMBLY, AND CHECKOUT

10.1 INTRODUCTION

Solid propellant rocket motor (SRM) segments, 156 in. in diameter, 27 ft long and up to 320,000 lb in weight, will be manufactured at Thiokol/Wasatch Division near Brigham City, Utah, and transported via rail to the Kennedy Space Center in Florida. Lifting devices and overhead cranes have been used in various USAF programs with SRM's of similar sizes and weights. Existing railcars have capacities that exceed the anticipated weights of the segments. Rail transportation has been cleared for shipment of loads up to 164 in. diameter from Corinne, Utah, to Kennedy Space Center in Florida. At the Space Center each segment and component will be inspected for shipping damage and placed in storage until required for stage buildup. Stage buildup will be accomplished by bringing each segment to the vehicle assembly building (VAB), breaking the segment into a vertical position and installing it on the matching segment. When stage assembly is complete the necessary checkouts and tests will be performed prior to mating the SRM stage to the Space Shuttle vehicle.

Because of segment geometry, case segments must be shipped with the longitudinal axis in a horizontal plane oriented fore and aft on the railcar. Case and propellant stresses during longitudinal, lateral, and vertical dynamic loading imposed by severe railcar coupling have been analyzed. For the analysis, loaded segments were assumed to be supported by saddles at each end, with vertical restraint bands and tiedown devices added to prevent the segment from moving laterally and vertically under dynamic loads. Bracing to restrain fore and aft movement was also assumed. Stiffeners were added to the open ends of the segments. The fundamental frequency for this configuration is well above the predominant railroad transport frequency (10 to 14 cps). Consequently, resonant frequency does not appear to present problems.

Data obtained from Department of Defense Research and Engineering Bulletin No. 31 indicates that longitudinal acceleration loads in excess of 10 g have occurred on a railcar during severe railyard handling (Figure 10-1). Under severe handling, vertical acceleration up to 5 g was attained. Lateral acceleration is insignificant (approximately 0.15 g). Fatigue loads in the range of 5 g during segment transport are acceptable. Propellant-to-liner failure (due to shear loading) could occur above 20 g; therefore, shock mitigation equipment is recommended only under severe handling conditions. Controlled handling during railcar coupling could eliminate requirements for shock mitigation equipment.

An analysis has been made of the propellant grain to determine temperature control requirements during segment shipment. Stresses and temperatures in the propellant grain and liner were examined for segments exposed to varying ambient temperatures. The analysis is based on Thiokol studies made during the development

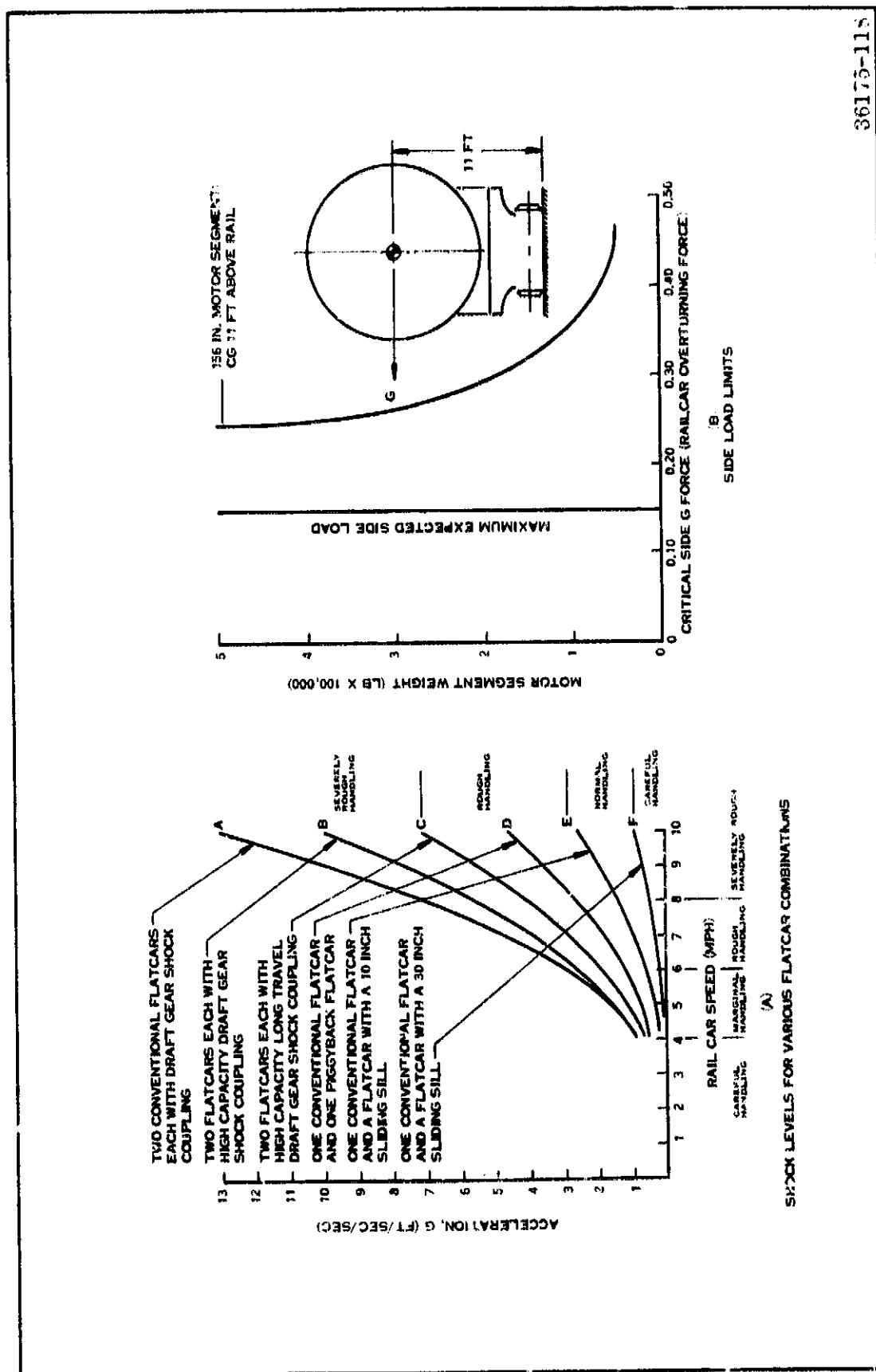


Figure 10-1. Longitudinal and Lateral Accelerations During Shipment

of the Thiokol 156-1 center segment under Contract AF 04(695)-363. The segment ends were sealed and the entire segment insulated with a 2 in. layer of fiberglass. The initial segment temperature was set at 80° F. A unidirectional (radial) heat transfer was assumed; also, stress relaxation (zero stress at 80° F) was assumed. Time of exposure was varied from 1 to 20 days.

Results of the analysis show the tangential and radial tensile stresses to be small, even at extremely low temperatures. SRM tangential and radial thermal stresses increase as the temperature decreases. These stresses, greatest at the case liner, were 6.3 psi and 0.9 psi at a temperature of 23° F (a 23° F case liner temperature corresponds to a -40° F, 10 day, temperature soak, Figure 10-2). Compressive stresses are not considered problematical. Grain temperature variation at different depths in the grain, during a 10 day interval, also showed the greatest temperature variation at the case liner area (Figure 10-2). For each extreme time-temperature condition analyzed (20 days at -4° and +140° F), temperature at the initial port burning surface area deviated less than $\pm 10^\circ$ F from its initial 80° F temperature. Propellant failure (cracking) occurs only at low temperatures; therefore, segment heating will be required only when segments are exposed to extremely low temperatures for long periods of time (Figure 10-2).

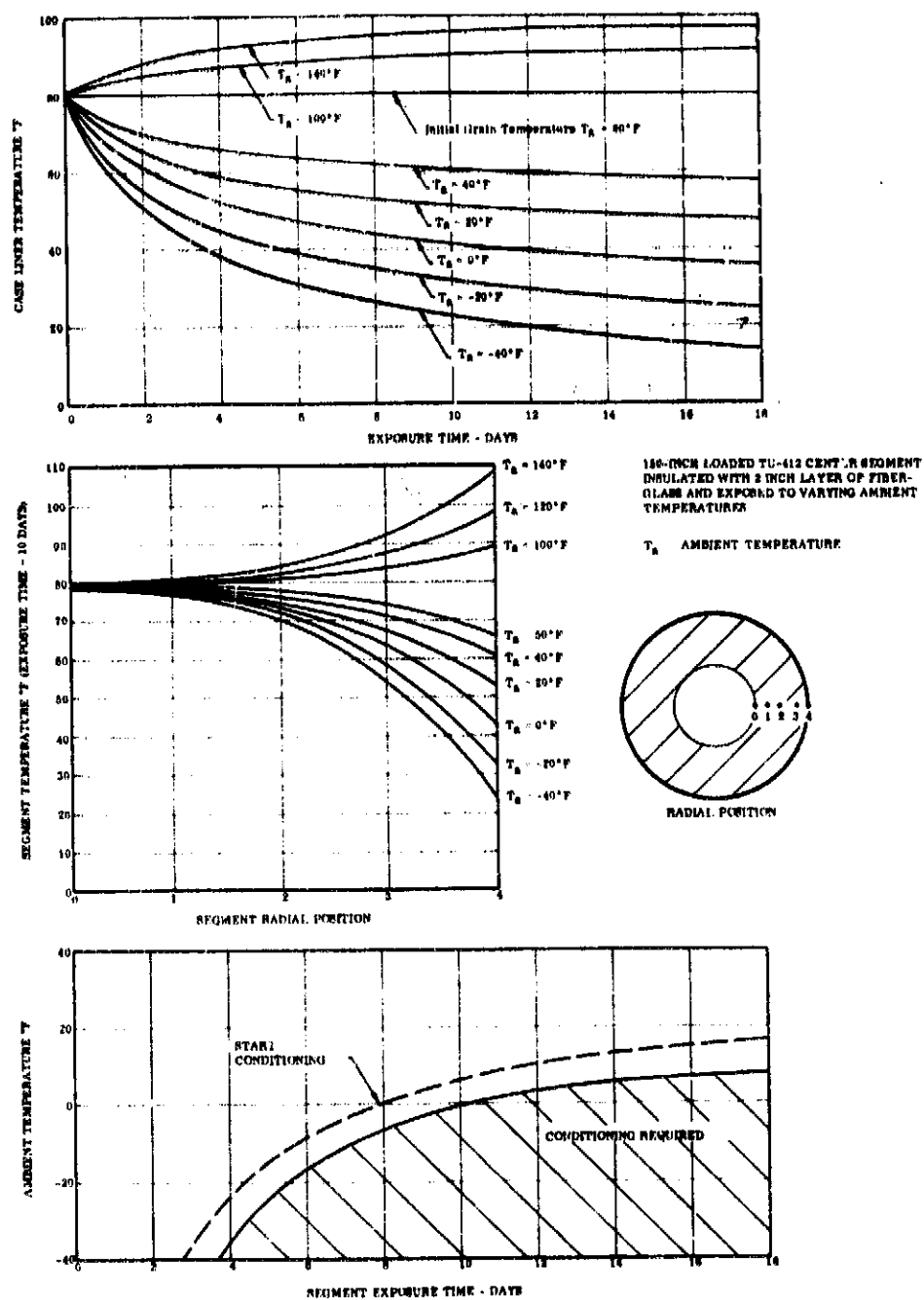
Based on this cumulative experience gained by Thiokol, the propellant grain need not be conditioned during segment transport to most locations in the continental United States. Neither will humidity control be required, based on data obtained from the Minuteman storage program. Segment storage for long periods (18 mo) under high temperature (100° F) and high relative humidity (75 percent) conditions is possible without degradation of the propellant. A combination of extreme temperature and humidity within the continental United States is a remote possibility unlikely to occur for long periods. Temperatures in Jacksonville, Florida, considered for design are 90° F (dry bulb) and 78° F (wet bulb); the highest temperature recorded since 1871 is 105° F. *

The primary analysis for transportation and handling of the SRM stage is generated around the 156 in. diameter "baseline" parallel configuration. Options to the "baseline" are discussed. Alternate configurations including the 156 in. diameter series configuration, 120 in. diameter parallel configuration, and 260 in. diameter series configuration were also reviewed.

10.2 TRANSPORTATION AND HANDLING OF GSE

It is anticipated that the various items of Ground Support Equipment (GSE) will be manufactured by different vendors located throughout the country. Some items will be required at Thiokol/Wasatch to be used in transporting the Solid Rocket Motor (SRM) segments. Some items will be shipped directly to the Kennedy Space

*Heating, Ventilating, and Air Conditioning Guide, Am Soc of Heating and Air Conditioning Engineers, 1959.



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Figure 10-2. Grain and Liner Temperature Data for 156 In. Diameter Loaded Segments

Center (KSC) for use in operations performed there. Still other items will be shipped directly to vendors who will use them in the shipping of SRM components.

Initial items fabricated will be shipped to Thiokol/Wasatch where the necessary tests and checkouts will be performed to verify performance. After satisfactorily passing the required tests, the items will then be shipped to their point of use.

10.2.1 Preparation for Shipment

Each item of GSE will be preserved and packaged in accordance with NASA requirements.

10.2.2 Shipment

After being properly preserved and packaged, each item of GSE will be shipped by the manufacturer directly to the location where the item is to be used. Shipment will be made by a common carrier in sufficient quantities to meet the required launch rate.

10.2.3 Receiving and Inspection

Upon arrival at its designated point, each item will be unpackaged and inspected for completeness and shipping damage. If satisfactory, each item will be placed in storage until required.

10.3 TRANSPORTATION OF SRM SEGMENTS

The SRM segments will be manufactured and prepared for shipment at Thiokol/Wasatch (Figure 10-3). Each segment will be preserved and packaged in accordance with NASA requirements. Identification and marking will be in accordance with NASA requirements.

Each shipment will consist of the required number of segments and parts to fabricate one SRM. For the parallel configuration, each shipment will consist of one aft segment, three center segments, and one forward segment. The size and weights of the segments are as follows.

<u>Item.</u>	<u>Shipping Size*</u> <u>Length (ft)</u>	<u>Shipping Wt</u> <u>(lb)</u>
Forward segment, including Pyrogen unit, less S & A (1 per SRM)	21	166,000
Aft segment, including nozzle (1 per SRM)	23.5	182,000
Cylindrical segment (3 per SRM)	23.5	325,000

*The shipping diameter of all segments is 13 ft 2 in.

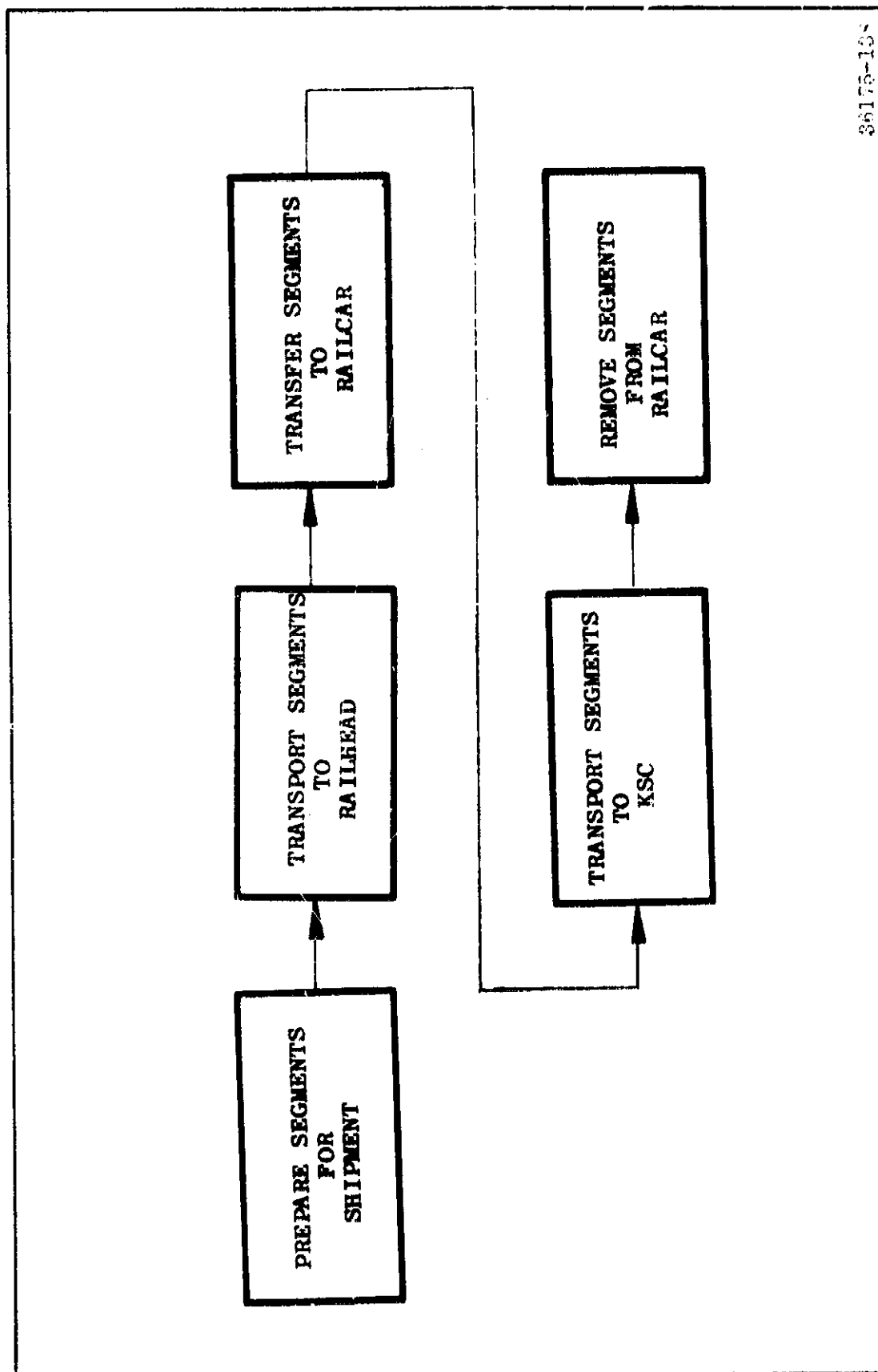


Figure 10-3. Transportation of SRN Segments to KSC

10.3.1 Preparation for Transportation

Each segment will be prepared for shipment by the Thiokol/Wasatch manufacturing personnel. The segment will be placed on special chocks on a semitrailer. Special tiedown attachments on the chocks will be attached to the segment. The tiedowns will be attached to the segment with wide, flexible straps that fasten to the chocks and over the top of the segment. The chocks will be butted up against the joints of the segment to prevent forward and aft movement. During highway transportation, the maximum g load that will be encountered are as follows: (a 1 g load is equal to the weight of the segment plus the weight of the transporter).

<u>Condition</u>	<u>Load</u>	<u>Factor</u>
1	Fore and Aft	2 g with 1 g down
2	Side	1/2 g with 1 g down
3	Vertical	3 g

Temperature and humidity conditioning will not be required during transportation; however, a cover will be required over each segment to protect the segment from direct sunshine inclement weather and damage while enroute.

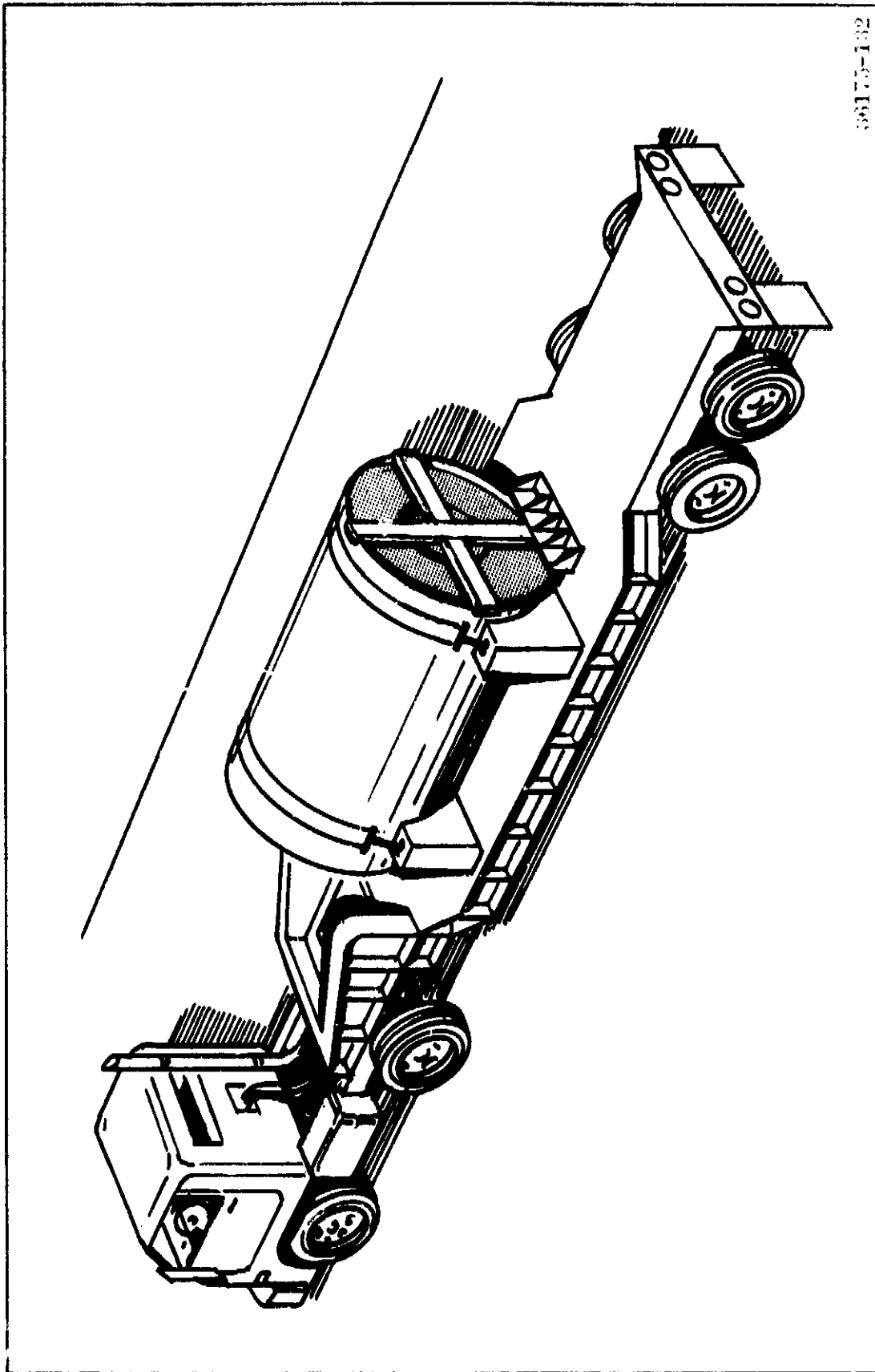
10.3.2 Transportation to Railhead

The segments will be transported from the manufacturing site to the nearest railhead at Corinne, Utah. Transportation will be by a special semitrailer-tractor combination that will be designed to carry the 325,000 lb maximum loads (Figure 10-4). Consideration will be given in the design of the semitrailer to conform with local axle loading requirements, which allow loads up to 50,000 lb per axle with special permits.

10.3.3 Transfer to Railcar

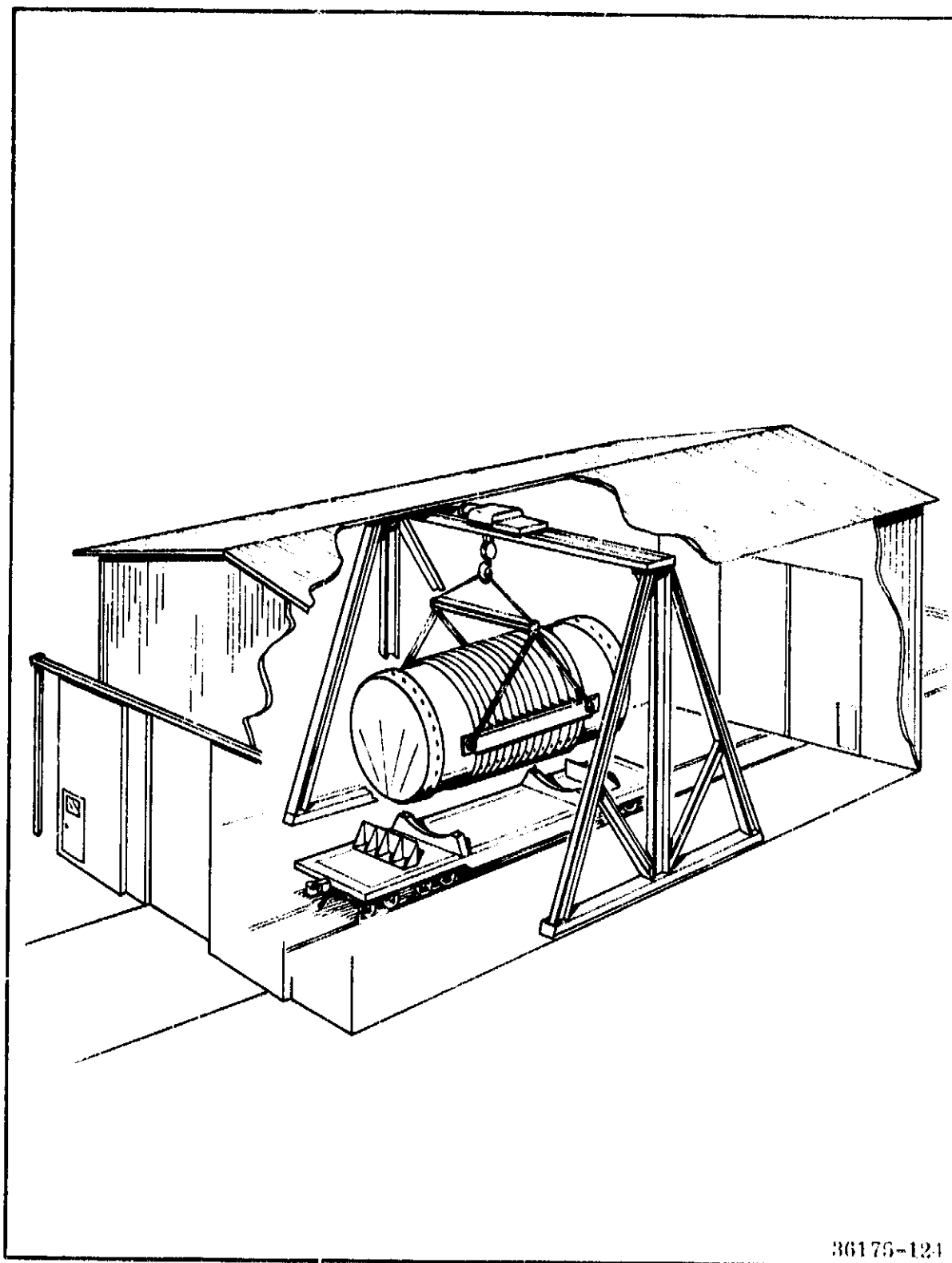
Upon arrival at the railhead, the segment must be transferred from the semitrailer to the railcar. The transfer will be made inside a building to be constructed which will provide protection during inclement weather. The protective cover and tiedown devices will be removed and a Pneuma-Grip lifting device will be installed on the segment.

The segment will be lifted from the semitrailer using a 200 ton gantry, and placed on special chocks on the railcar (Figure 10-5). The lifting device will be removed, the tiedowns installed and the protective cover attached to the segment. The segment will then be ready for shipment. This process will be repeated until one aft segment, one forward segment and either three or four center segments are loaded on flat cars. Only one segment will be loaded on any one car. Load limitations



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Figure 10-4. Transportation of SRM Segment to Railhead



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Figure 10-5. Transferring Segment to Railcar

on various bridges and trestles encountered along the route will require that empty cars be placed between the loaded cars for weight distribution.

The support chocks on the railcars will not be permanently attached but will be adjustable to compensate for different segment lengths. The chocks and tiedowns will be designed to withstand loads as follows: (1 g is the weight of the segment).

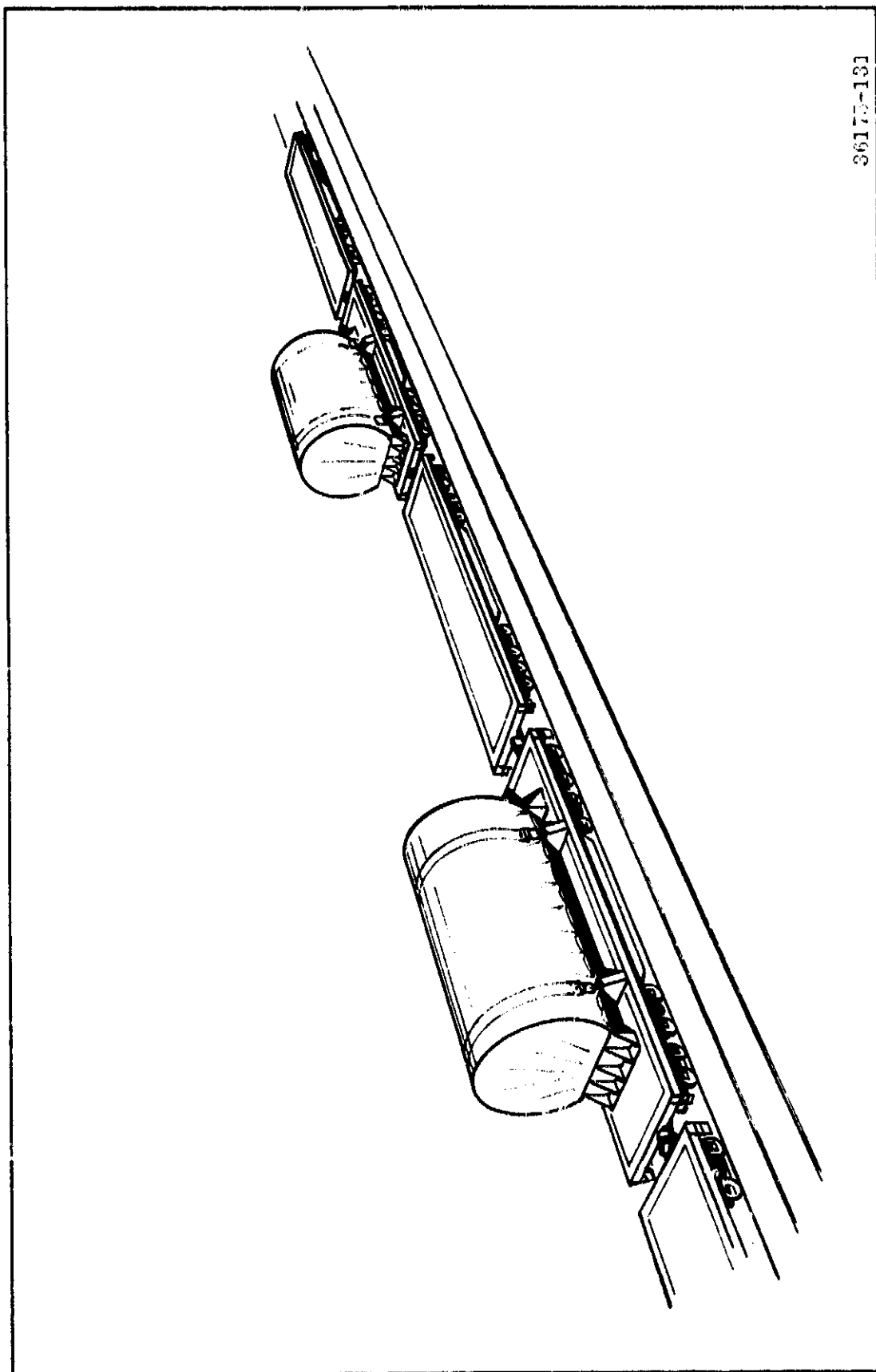
<u>Condition</u>	<u>Load</u>	<u>Factor</u>
1	Fore and Aft	3 g with 1 g down
2	Side	1/2 g with 1 g down
3	Vertical	3 g

10.3.4 Transportation to Kennedy Space Center

Due to the size and weight of the segments being transported, railroads offer the most cost effective means of transportation (Figure 10-6). Transportation by air or highway is feasible but not economical at the present time. Shock mitigation will be provided by controlling the speed of the railcars during all coupling and uncoupling operations to 5 mph or less. It will take approximately two weeks to transport the segments from Utah to Kennedy Space Center, Florida. Speeds will be limited to 45 mph on straightaways and 35 mph around curves.

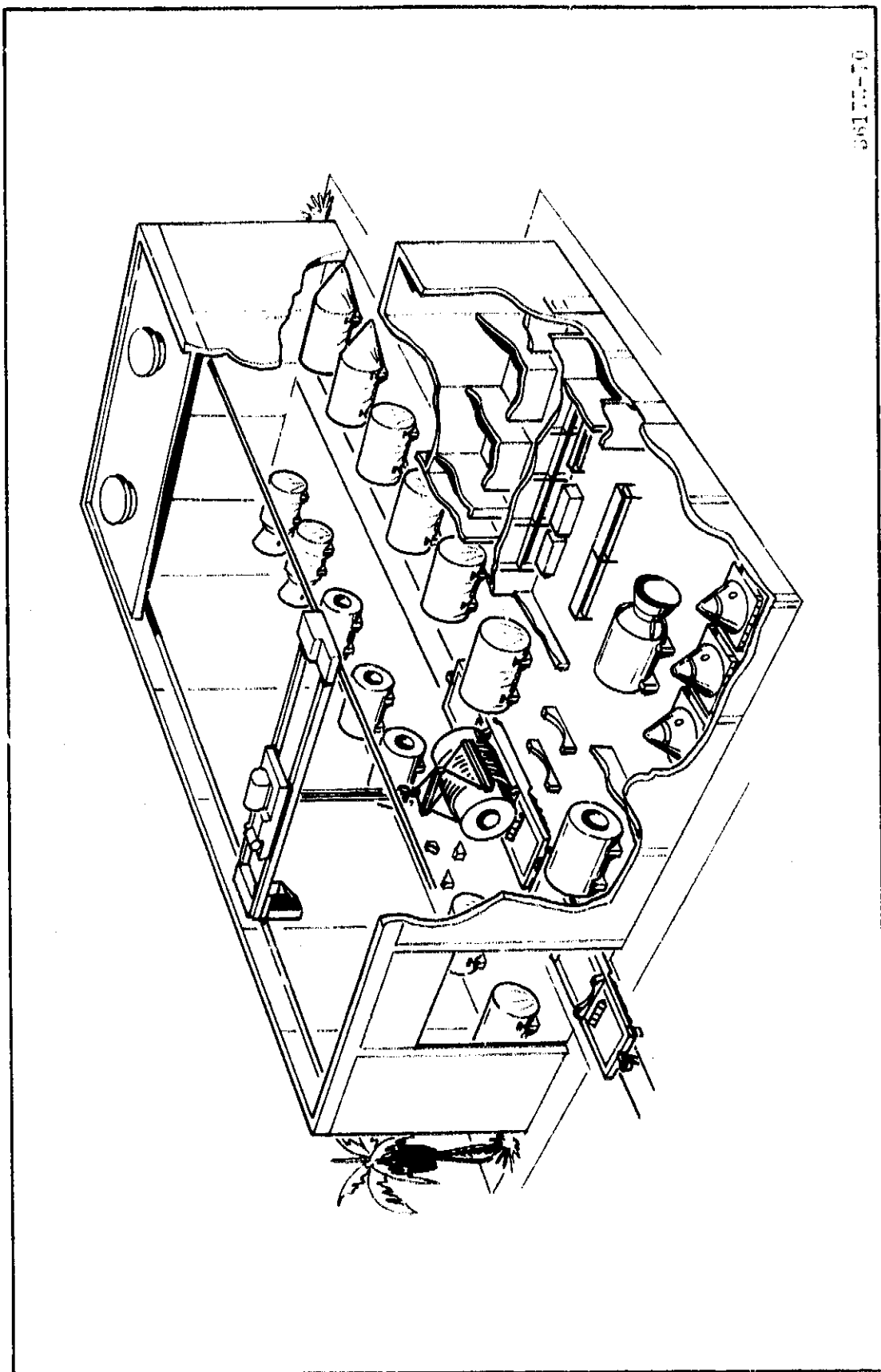
10.3.5 Segment Receiving and Inspection

The segments will be transported directly to a newly constructed receiving, inspection, storage, subassembly (RISS) building (Figure 10-7). They will be off-loaded from the railcar using a Pneuma-Grip lifting device and a 200 ton bridge crane in the building. Each segment will be placed on storage chocks and inspected for shipping damage. If there is no damage, the segments will remain in storage until required for SRM stage buildup.



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Figure 10-6. Shipping Segments by Rail to Assembly Site



36173-70

Figure 10-7. Receiving, Inspection, Storage, Subassembly (RISS) Facility

10.4 TRANSPORTATION AND HANDLING OF AFT SKIRT EXTENSION, NOSE CONE, ATTACH STRUCTURE, AND MISCELLANEOUS COMPONENTS

The aft skirt extension, interstage structure, nose cone, various ordnance items, electrical components, etc, will be manufactured by various vendors (Figure 10-8). Each vendor will be responsible for manufacturing and shipping their items in sufficient quantities to satisfy the launch rate.

10.4.1 Preparation for Shipment

Each item will be preserved and packaged in accordance with NASA requirements. All packages will be marked in accordance with NASA requirements.

10.4.2 Shipment of Components

After being properly preserved and packaged, each item will be shipped by common carrier to Kennedy Space Center. Shipment will be made in the most economical method to meet launch schedules.

10.4.3 Receipt and Inspection of Components

Upon arrival at the Space Center, each item will be unpackaged and inspected for shipping damage. If no damage is evident, the item will be stored until required for SRM stage buildup.

10.5 SEGMENT SUBASSEMBLY

To facilitate SRM stage buildup in the VAB, certain subassembly tasks will be performed in the RISS building prior to transporting the segments to the VAB.

10.5.1 Installation of Aft Skirt Extension on Aft Segment

The aft skirt extension will be lifted from its shipping container with an overhead crane and lifting device. The skirt will be rotated and aligned with the aft segment. The skirt will be properly positioned and the attach hardware installed.

10.5.2 Installation of Nose Cone on Forward Segment

The lifting device will be attached to the nose cone and the nose cone will be lifted with an overhead crane and aligned with the forward segment. The nose cone will then be installed on the forward segment and the attach hardware installed.

10.5.3 Installation of Attach Structure

The attach structure will be installed on the forward and aft segments. A lifting sling will be attached to the attach structure and an overhead crane will lift the structure into position. The attach hardware will be installed.

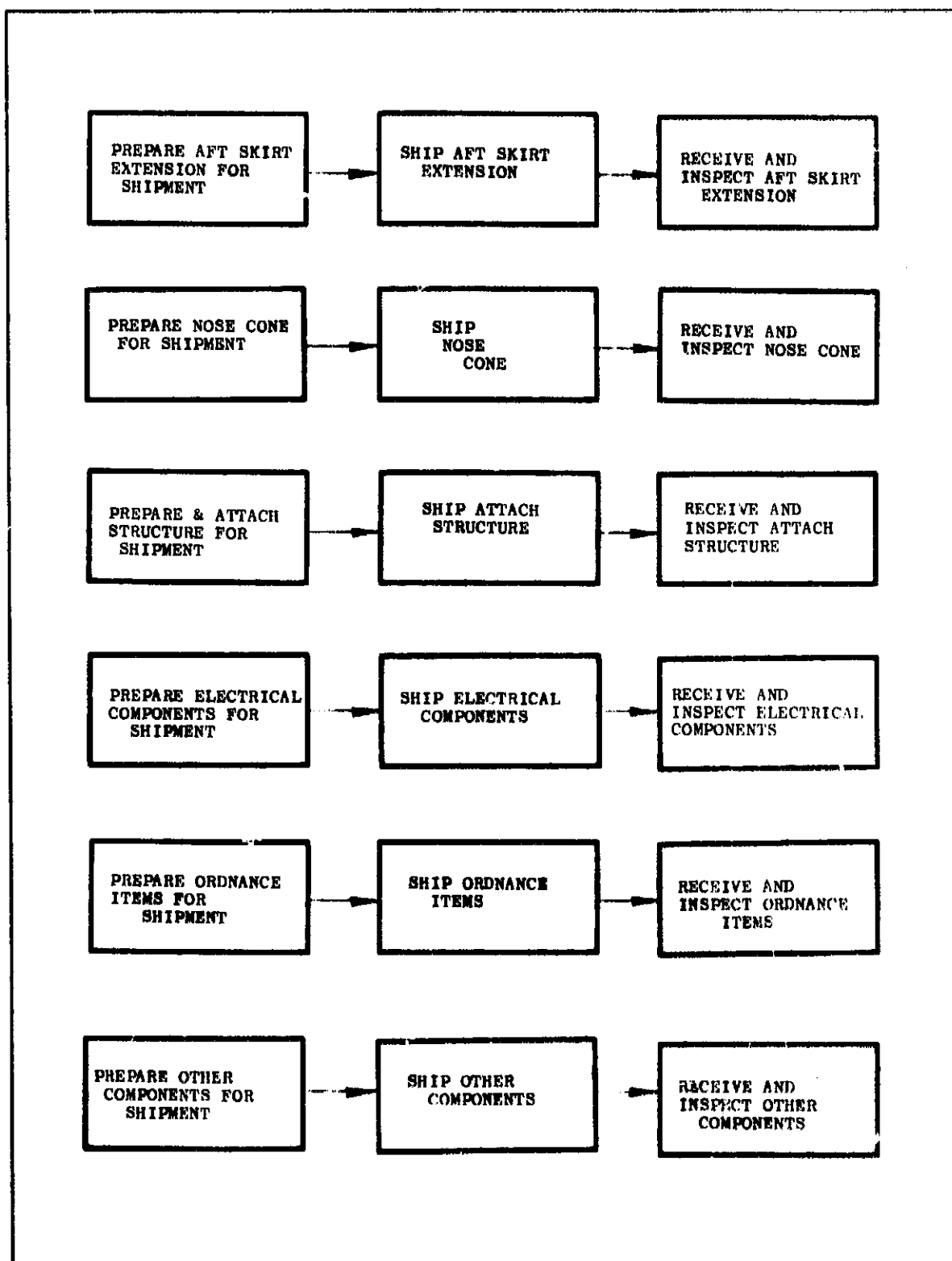


Figure 10-8. Transportation and Handling, Aft Skirt Extension, Nose Cone Attach Structure, and Miscellaneous Components

10.6 TRANSPORTATION OF SEGMENTS AND COMPONENTS TO VAB

SRM stage buildup will be performed in the vehicle assembly building (VAB). The segments and components will be transported over a special roadway which must be provided from the RISS area to the VAB for motor buildup (Figure 10-9).

The components are generally small enough that they can be transported on flatbed or pickup trucks. The segments must be transported on special semi-trailers similar to those used for transporting the segments to the railhead in Utah.

10.6.1 Preparing Segment for Transportation

The segments are stored on chocks in the RISS building. Each segment will be prepared for transportation by removing the protective covers and insuring that the joint stiffeners are securely in place.

10.6.2 Transferring Segment to Semitrailer

The segment will be transferred to the semitrailer by positioning the semitrailer next to the segment. The pneumatic lifting device will be installed on the segment and the segment will be raised and positioned over the semitrailer chocks. The segment will then be lowered onto the chocks and the lifting device removed.

10.6.3 Securing Segment for Transportation

The segment will be secured for transport by installing tiedown devices. Grounding straps will be installed. Protective covers will be fastened on the segment if it is raining or threatening to rain.

10.6.4 Transporting Segment to VAB

When the segment is properly tied down on the semitrailer, it will be taken to the VAB where it will be assembled into the SRM stage.

10.6.5 Preparing Segment for Transfer

Upon arrival at the VAB, the semitrailer will be positioned near the break-over stand. The protective cover, if installed, will be removed. The tiedowns and grounding straps will be disconnected.

10.6.6 Removing Segment from Semitrailer

The pneumatic lifting device will be installed on the segment. The segment will be lifted from the semitrailer and positioned in a breakover stand. The breakover

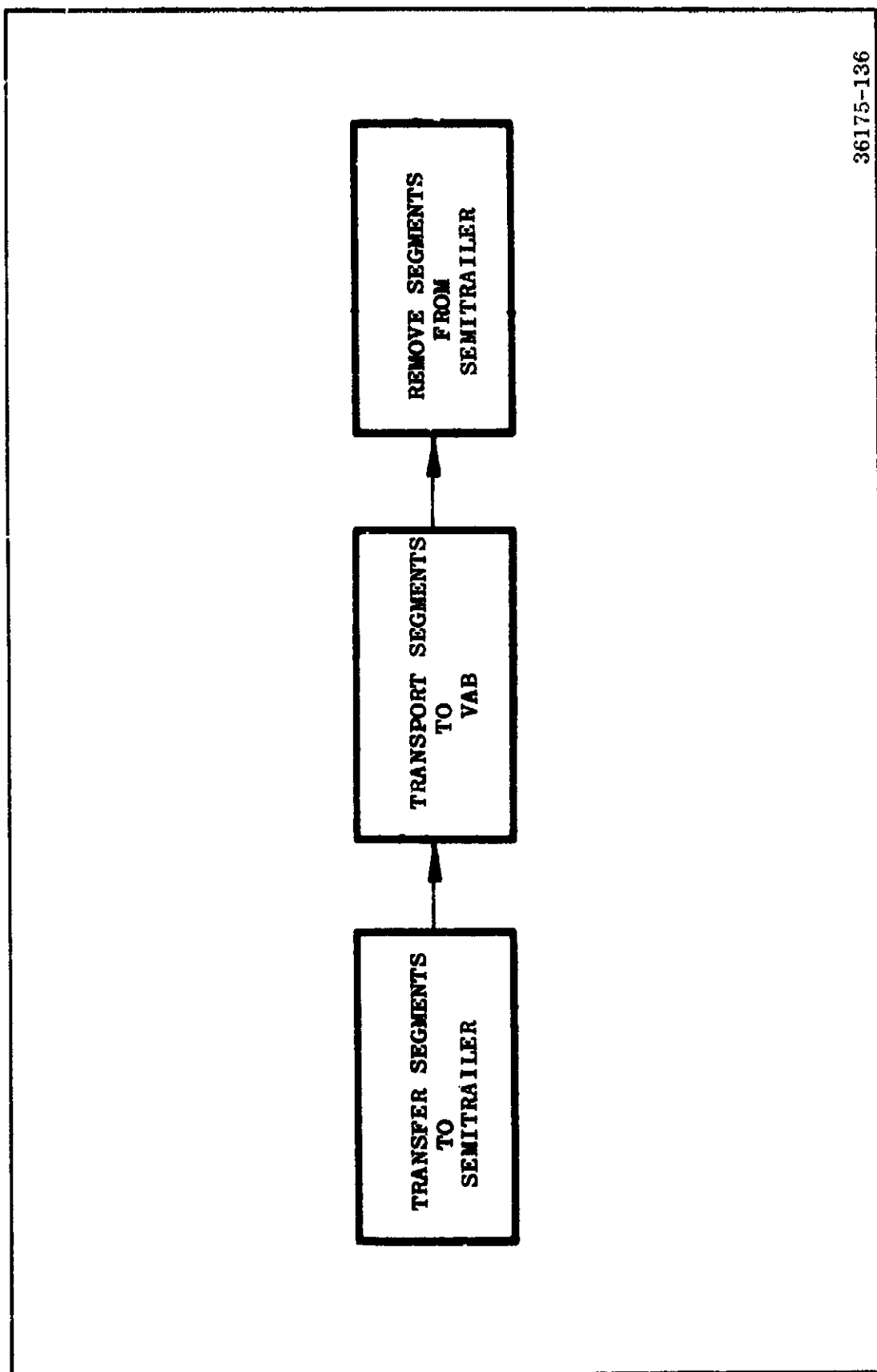


Figure 10-9. Transportation of SRM Segments to VAB

stand will interface with trunnions on the lifting device. The stand will support each loaded segment in a horizontal position. The segment will be simultaneously lifted from the breakover stand and rotated to a vertical position.

10.7 SRM STAGE ASSEMBLY AND CHECKOUT

Each SRM will be built up segment by segment until it is completely assembled (Figure 10-10). The stage will be assembled on the launch platform base of the mobile launcher. The launch platform shall provide the capabilities of adjusting the SRM's for proper alignment. Stage assembly will be done in a vertical attitude using a pneumatic lifting device and lifting beam similar to that used in the RISS building.

The VAB will have hoisting equipment with the capacities and precision adjustment capabilities required to lift and assemble the segments and various other items.

10.7.1 Positioning Aft Segment Subassembly on Launch Platform

The aft segment subassembly will be broken over to a vertical position using the pneumatic lifting device, the breakover stand, and the VAB crane (Figure 10-11) and will then be lifted into position over the launch platform. The segment subassembly will be lowered until the aft skirt extension mates with the launch platform. The lifting device will then be removed and the segment and skirt will be aligned as required using the adjustment devices on the launch platform.

10.7.2 Assembling Center Segment on Aft Segment

Before the first center segment can be attached to the aft segment, the case stiffeners must be removed and the mating clevis joints cleaned and lubricated. The O-rings will be installed in the aft segment. The center segment will then be broken over to a vertical position and lowered to the floor where the lower case stiffeners will be removed. The segment will then be raised into position over the aft segment and lowered until the segments mate. The crane will be used to support and align the segment until the attach hardware can be installed. The lifting device will then be removed. The upper case stiffeners will be removed, the clevis joint cleaned, the O-rings installed and the next center segment installed.

10.7.3 Assembling Forward Segment Subassembly

After the final center segment is installed the forward segment will be attached to the final center segment (Figure 10-12) using the same procedure as was used in installing each of the center segments.

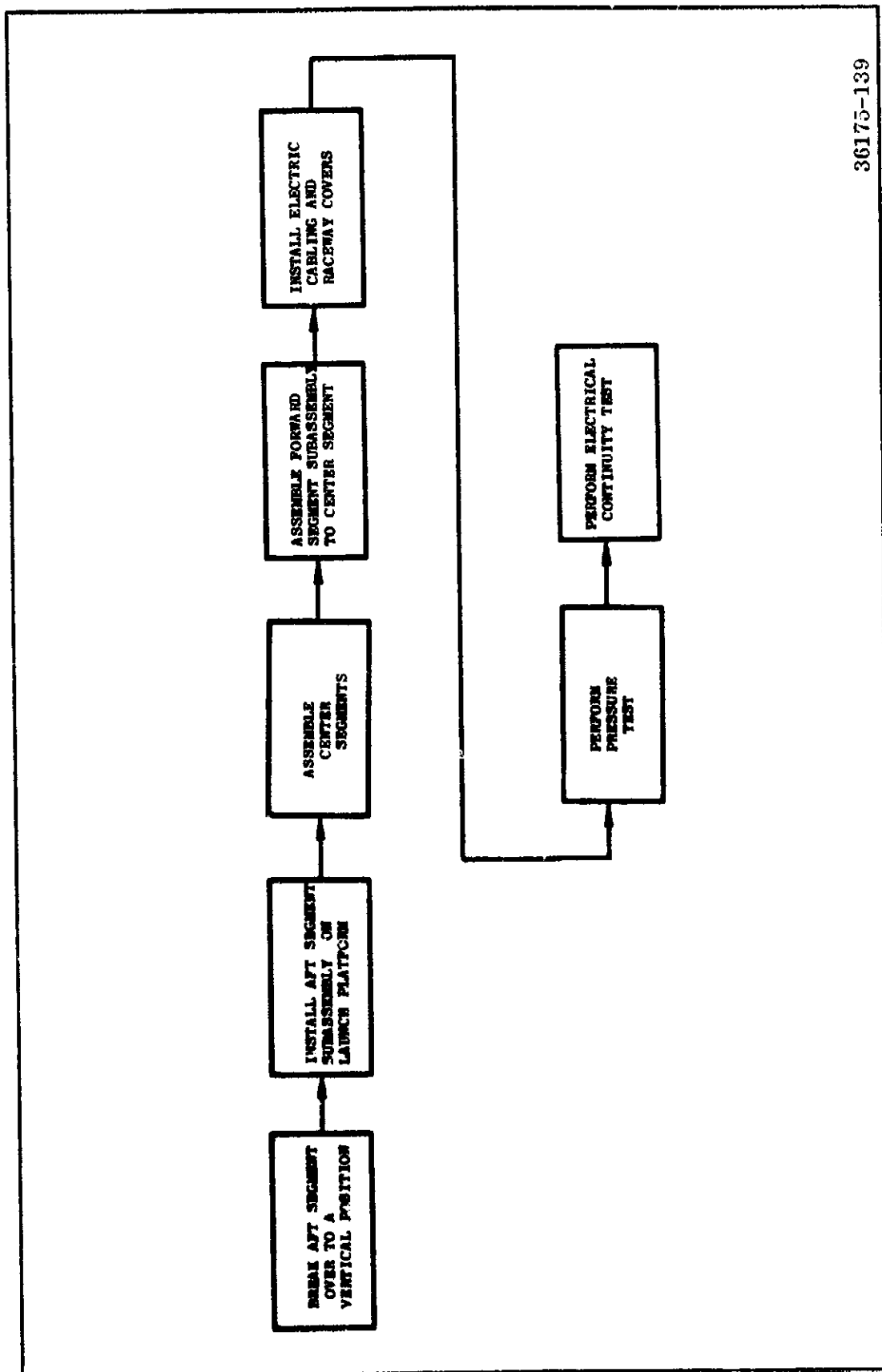
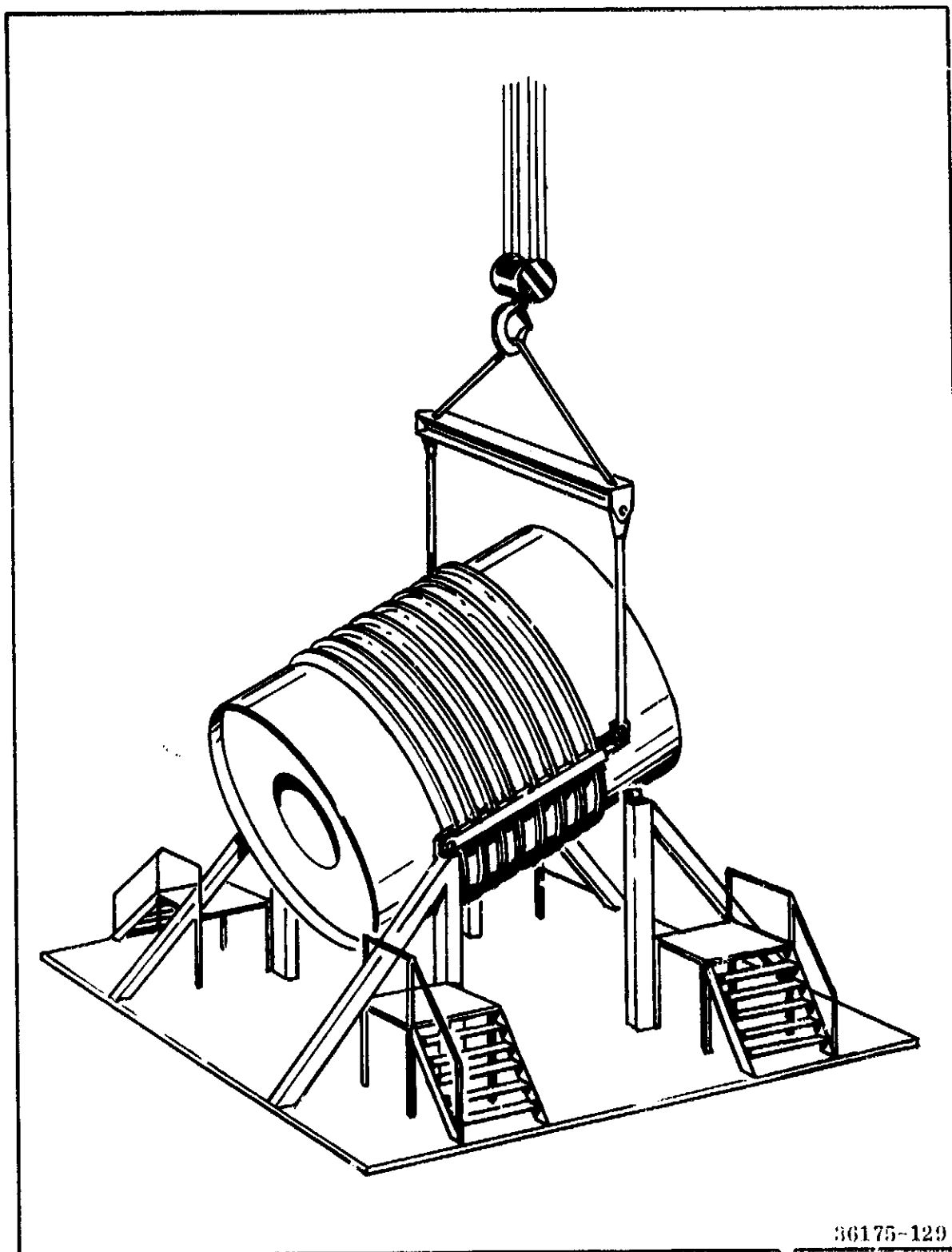


Figure 10-10. Assembly and Checkout of SRM Stage



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Figure 10-11. Breakover of SRM Segment

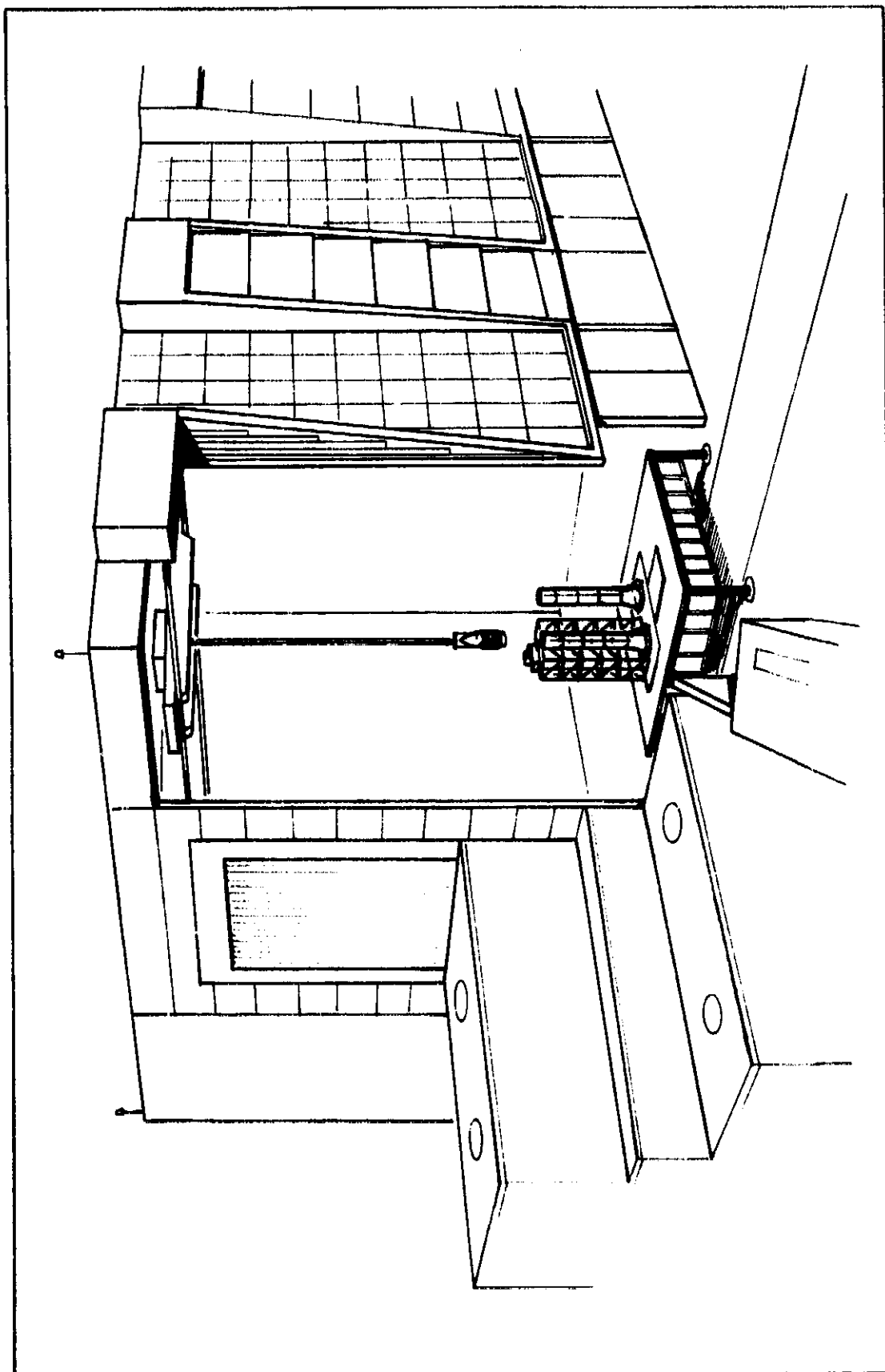


Figure 10-12. Assembly of Segments into Stage

10.7.4 SRM Stage Checkout

When the SRM is completely assembled, it will be necessary to perform electrical continuity checks and pressure tests of the case joints.

10.7.4.1 Continuity Test

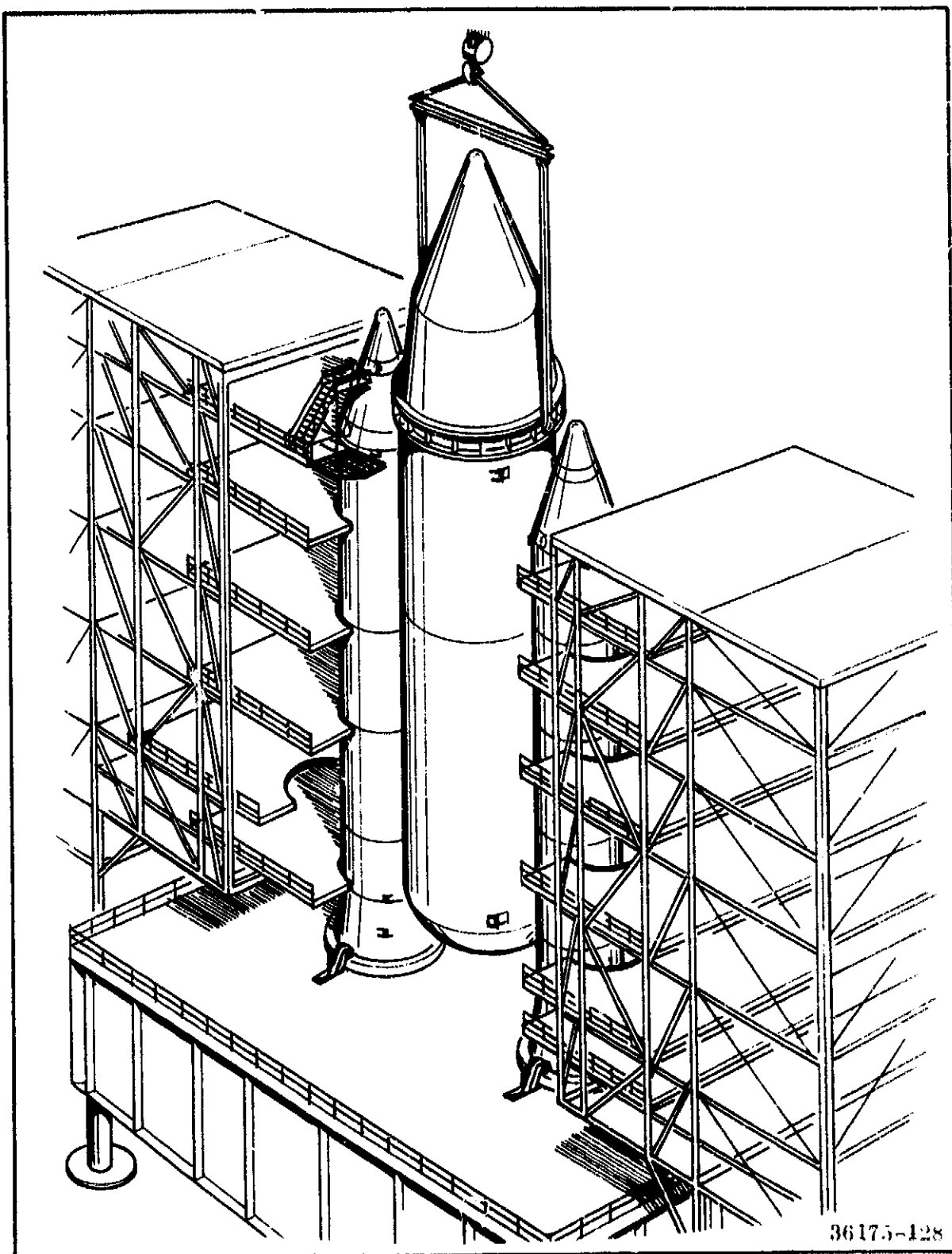
The continuity test will consist of completely checking the electrical systems for continuity. To complete this task, the cap must be removed from the nose fairing to provide access to the forward dome area.

10.7.4.2 Pressure Test of Case Joints

To insure integrity of the various joints and seals, the SRM case will be pressurized to 30 psi, the supply pressure cut off, and the internal pressure monitored for 30 min for decay. The pressure test will be performed by sealing the nozzle throat and pressurizing the motor with nitrogen.

When the SRM stages have been completely assembled and checked out, the orbiter components will be attached to the interstage structures by the Space Shuttle contractor (Figure 10-13).

With the orbiter completely installed, all necessary electrical connections will be made and final electrical checkouts will be performed by NASA (Figure 10-14). The system will then be ready for transport to the launch pad (Figure 10-15).



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Figure 10-13. Assembly of Space Shuttle Fuel Tank

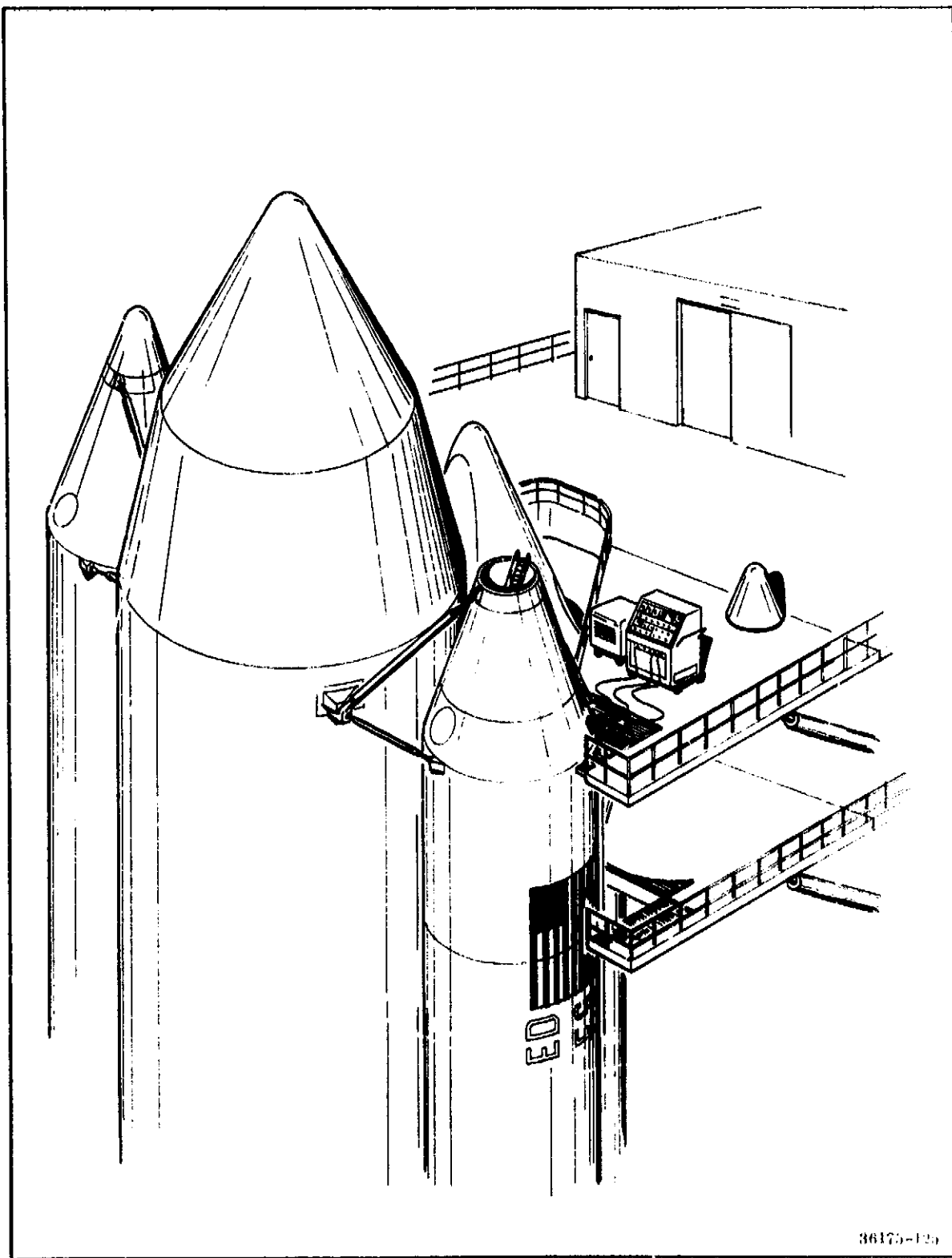
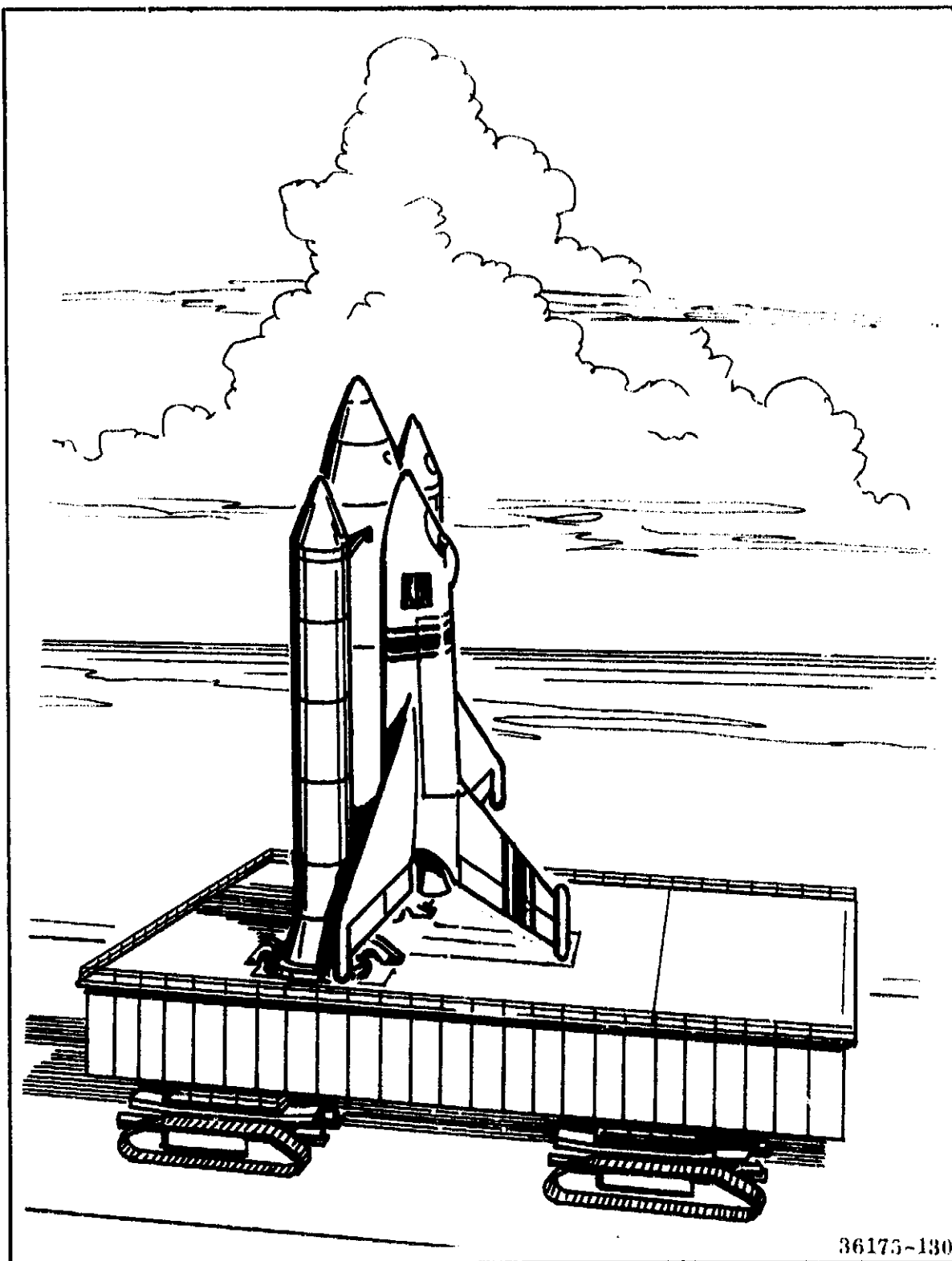


Figure 10-14. Final Checkout of Electronic Components



36175-130

Figure 10-15. Transportation to Launch Site on Mobile Launcher

10.8 MANPOWER REQUIREMENTS

The tasks required to perform the various transportation, handling and assembly functions were identified in the systems requirements analysis (SRA). The manpower and the approximate time required to perform each task were also identified in the SRA. Time line analysis of the various tasks was used to establish the total direct manpower requirements for each program. Support functions were identified in relation to the operations required and direct manpower required. The total manpower requirements for the 156 in. diameter parallel program at various production rates are shown in Table 10-1.

10.9 OPTIONS

The operations described thus far are concerned only with the baseline rocket motor. Addition of the various options will have an effect on the equipment requirements. The effect on facilities and manpower are minimal because scheduling will allow the additional operations to be performed during generally slack time or on short periods of overtime as required. The various options and their requirements are as follows.

10.9.1 Thrust Vector Control (TVC)

The TVC nozzle and hydraulic power unit (HPU) will be installed on the aft segment of the SRM at Thickol.

Nozzle shipping links will be designed to secure the nozzle during shipment. Functional checkout of the nozzle and HPU will be performed at the RISS building, the VAB, and on the launch pad.

Checkout at VAB will be restricted to cold gas operation of the HPU and controls. This check will require both the actuation system checkout console and the pneumatic regulation unit defined herein. Checkout on the launch pad will consist of cold gas functional operation checks during the control system final verification. During the final periods of countdown prior to launch, a full-up (completely on internal equipment) hot run on the HPU and control devices will be performed. The HPU has dual ignition capabilities and the initiator unit will be replaced after ground check. There is sufficient fuel for two complete ignition cycles and operational needs of each HPU. The control system will be completely checked out with the use of the checkout console. Checkout tests will cover all operating modes including abort and shutdown. The entire system will be operated in emergency conditions of partial shutdown of one unit and full shutdown of one unit.

TABLE 10-1

MANPOWER REQUIREMENTS (156 IN. PARALLEL)

Personnel	GTM & FTM		Production					
			10/yr		20/yr		40/yr	
	Direct	Support	Direct	Support	Direct	Support	Direct	Support
Test Engineer	1		1		2		3	
Data Technician	1		1		2		3	
Liaison Engineer	1		1		4		6	
Truck Driver	1		1		4		6	
Mechanic		1		1		4		6
Inspector	1		1		4		6	
Quality Engineer	1		1		3		3	
Crane Operator	1		1		4		6	
Operator	3		3		12		24	
Safety Engineer		1		1		2		3
Leadman		1		1		2		4
Field Engineer		1		1		1		2
Office and Administration		2		2		2		3
	10	6	10	6	35	15	57	20

GTM assumptions: Operations will be performed on a one crew, one shift basis with overtime as required.

Production flights--three day buildup at 40 and 60/yr. Nine day buildup at 10 and 20/yr

Assume 3 shifts per day, 60/yr

Assume 2 shifts per day, 40/yr

Assume 1 shift per day, 20/yr and 10/yr

The following components will be checked out:

1. TVC actuator
2. Hydraulic power unit controls
3. Pneumatic regulation unit

10.9.2 Staging

Staging will be accomplished by the thrust of small rocket motors mounted on the nose cone and aft skirt extension of the SRM. The staging rockets will be installed at Kennedy Space Center (KSC). The staging motors will be manufactured at Thiokol and shipped to KSC in reusable containers. The nose cone and other components will be shipped directly to KSC where they will be assembled. The staging motors will weigh approximately 40 lb.

10.9.3 Destruct

The destruct components will be shipped directly from the manufacturer to Thiokol for installation. The destruct components are small enough and of such a configuration that special handling equipment will not be required. As many of the destruct components as possible will be installed at Thiokol before the segments are transported to KSC. Final assembly of the destruct system will be performed in the VAB.

10.9.4 Refurbishment

Refurbishment of SRM cases will have significant effects on equipment and manpower requirements. Because of this, refurbishment is considered separately. Refurbishment will commence as soon as the SRM is aboard the recovery ship. It is assumed that the recovery ship will be procured and operated by NASA. Thiokol will operate the refurbishment equipment and perform the refurbishment operations done aboard ship. It is further assumed that cranes with 60 ton capacity will be available to lift the SRM from the ship to the dock and provide lifting capabilities during disassembly operations. Primary consideration is given here for the 156 in. diameter parallel configuration only. The recovery, disassembly, and refurbishment operations are as follows.

10.9.4.1 Recovery

As soon as the expended SRM's are aboard ship they will be hosed down using fresh water at a flow rate of approximately 120 gpm and a pressure of 150 psig. It will take from 10,000 to 15,000 gal of fresh water to flush off the two SRM's (Figure 10-16).

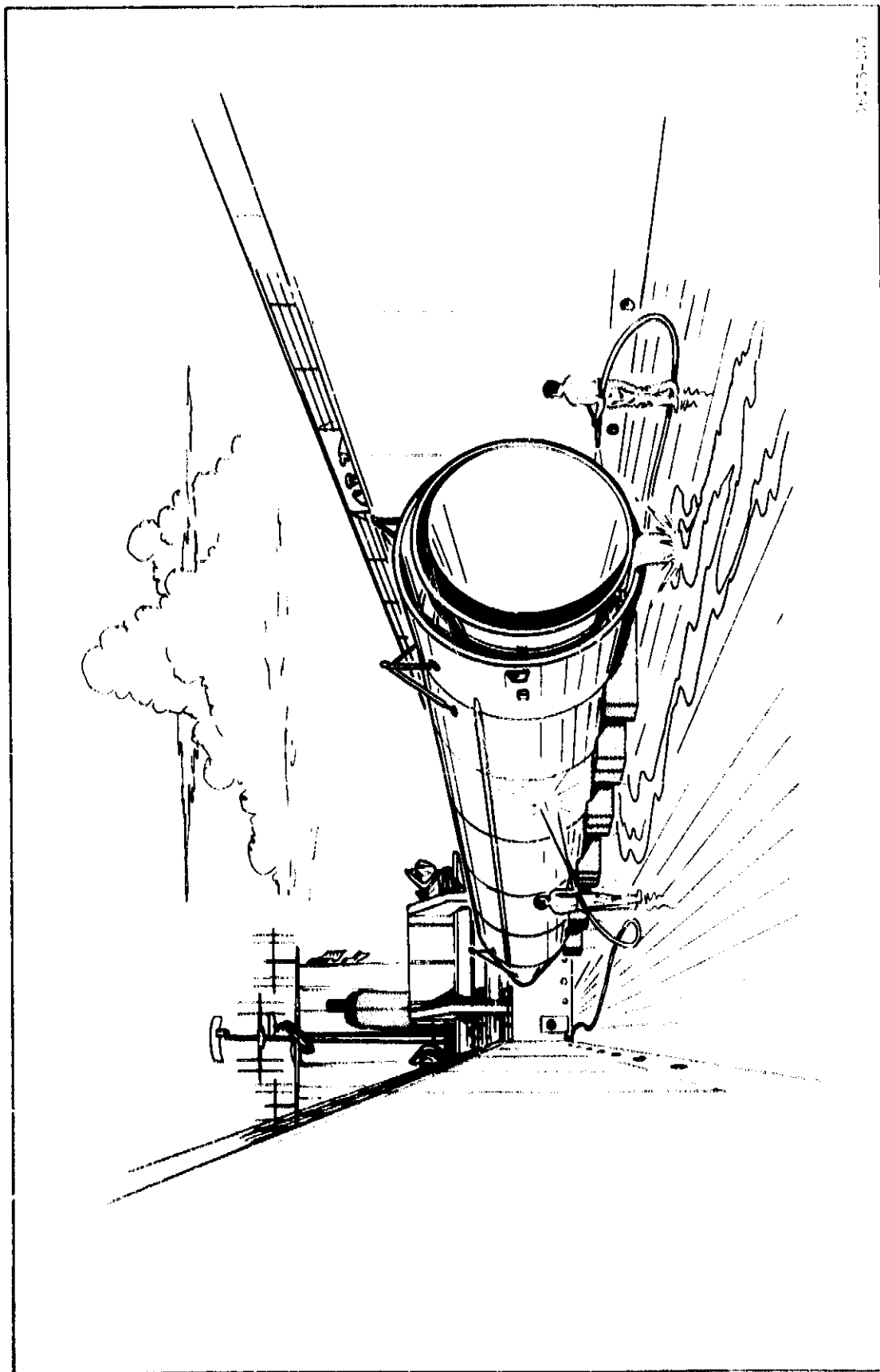


Figure 10-16. Washing SRM Aboard Ship

Once the SRM's have been hosed down, the HPU will be removed and cleaned using fresh water and then sprayed with an oxidation inhibitor. The turbine will be thoroughly flushed with fresh water and sprayed with a mixture of nitrogen and oil, atomized at a pressure of 1,100 psig.

10.9.4.2 Removal from Ship

Upon arrival at the dock site, the expended SRM will be removed from the ship (Figure 10-17). Each SRM will weigh approximately 126,500 lb. The SRM will be placed on a set of chocks on the dock and then disassembled by Thiokol personnel.

10.9.4.3 SRM Disassembly

Each SRM will be disassembled and the various components either disposed of or transferred to the RISS building for further processing or refurbishment. All expended ordnance items, electrical cabling and raceway covers will be disposed of. All other items will be considered for refurbishment.

10.9.4.3.1 Nozzle Removal

The nozzle, which will weigh approximately 13,000 lb, will be removed using a special lifting device and overhead crane. The attach hardware will be disposed of, and the nozzle shipped to the RISS building for further processing.

10.9.4.3.2 Aft Skirt Extension Removal

The aft skirt extension, which weighs approximately 12,000 lb, will be removed and disassembled. The components will be transported to the RISS building for further processing and refurbishment.

10.9.4.3.3 Interstage Structure Removal

The interstage structure, which weighs approximately 5,200 lb, will be removed and disassembled. The components will be transported to the RISS building for further processing and refurbishment.

10.9.4.3.4 Segment Disassembly

The various SRM segment cases, which weigh approximately 20,000 lb each, will be disconnected and transported to the RISS building.

The segments will be disassembled by installing the pneumatic lifting device on one of the end segments (Figure 10-18). Using the overhead crane to relieve pressure on the joints, the attach hardware will be removed using a special pin puller and standard tools. When the segment is disconnected, it will be lifted from

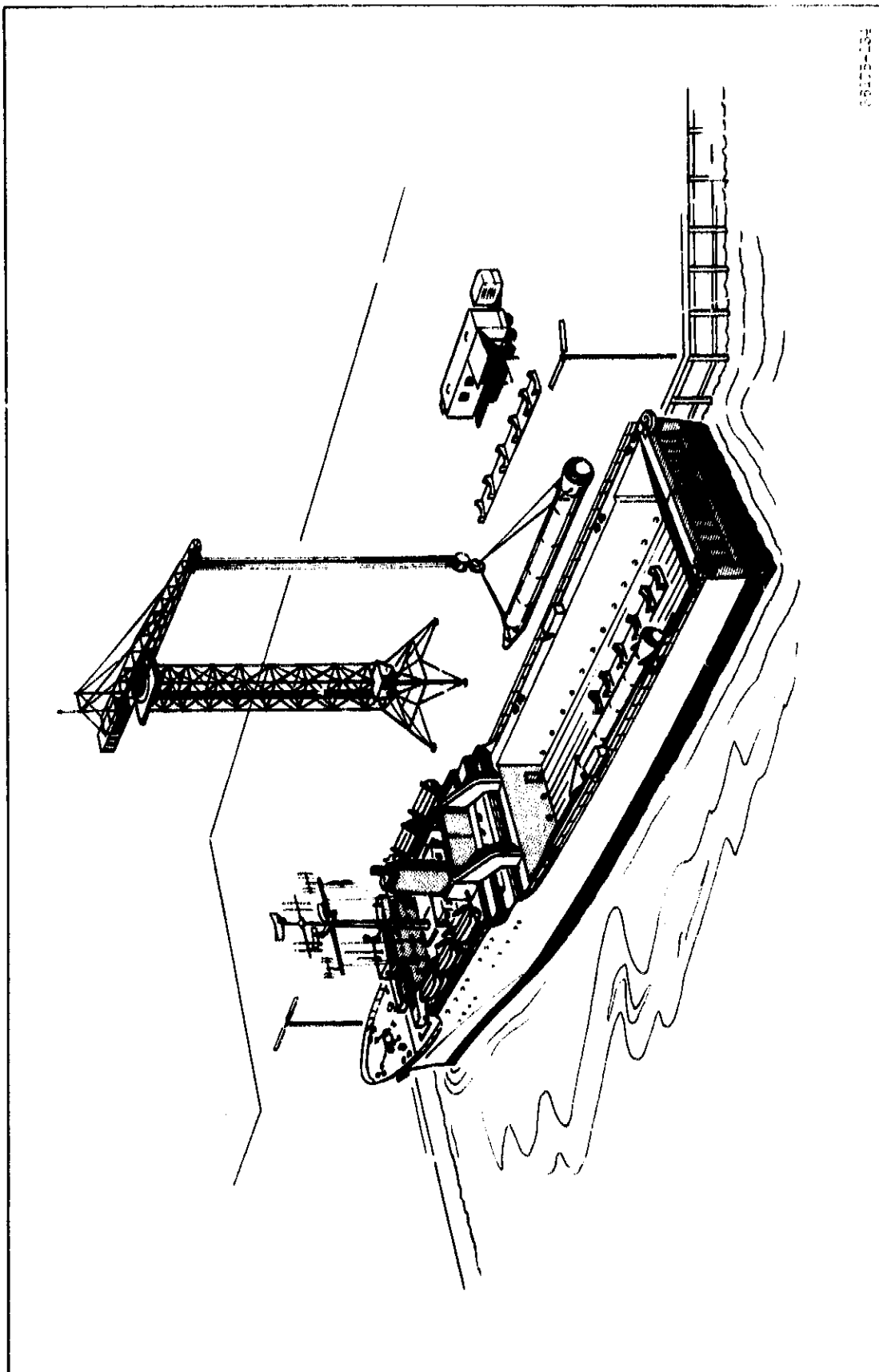
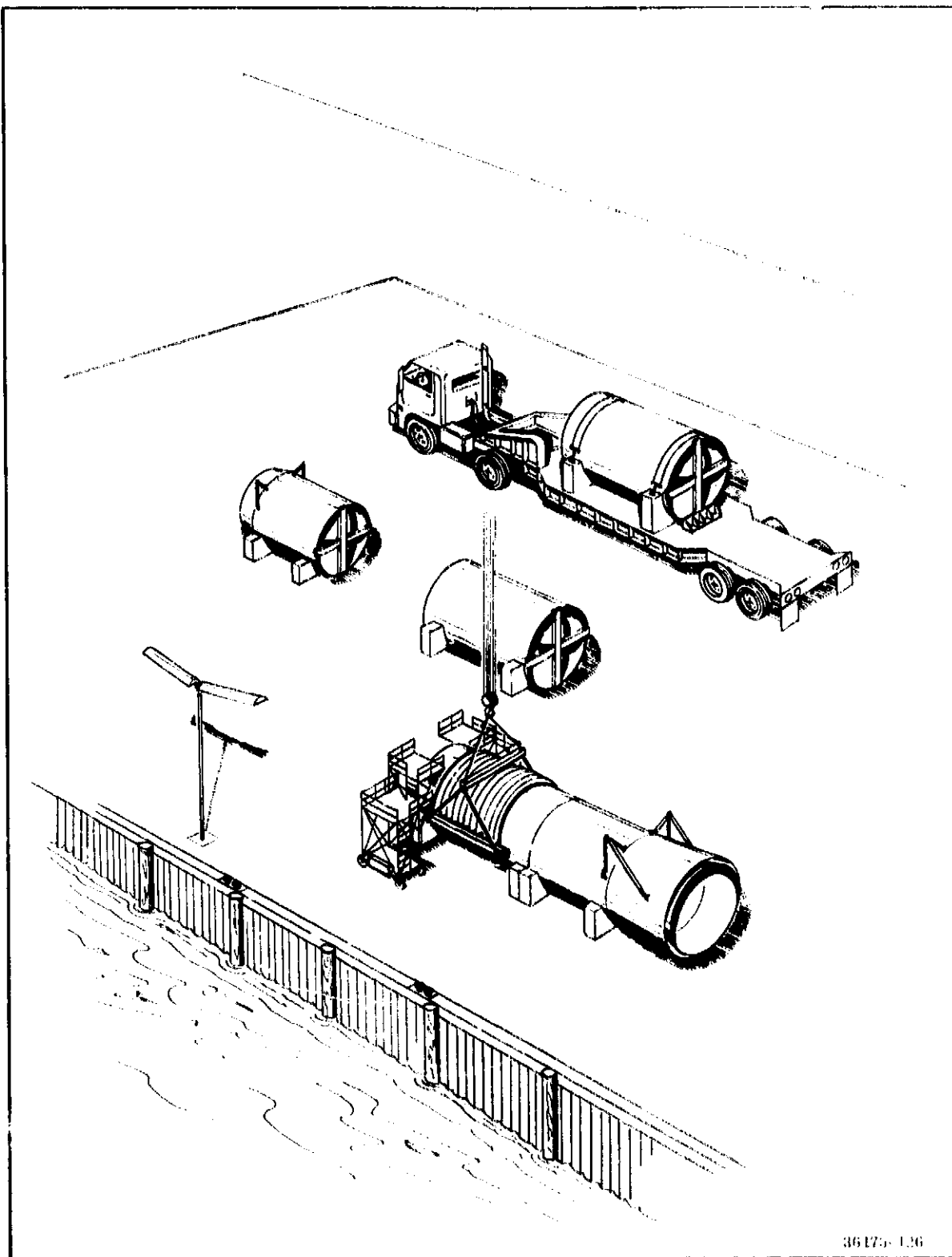


Figure 10-17. Removing SRM from Ship



36175-126

Figure 10-18. SRM Disassembly

the support chocks and either placed in another set of chocks or on the transporter. A bridge crane will be used to provide mobility to disassemble the segments and place them on the transporter. The same case stiffeners used on the loaded segments will be used on the empty segments.

10.9.4.4 Component Inspections

At the RISS building all of the components that are candidate for refurbishment will be inspected for unreparable damage.

If determined to be reusable, the following components, will be packaged or otherwise prepared for shipment to Thiokol/Wasatch or the appropriate manufacturer for reuse.

1. Case segments
2. Nozzle
3. HPU
4. Electronics

10.9.4.5 Refurbishment at Kennedy Space Center

If the interstage structure, aft skirt extension, and attaching hardware are deemed reusable, they will be cleaned and repaired as required. All components will be degreased, grit blasted, and painted. Parts that are not reusable will be replaced with spares from stock.

10.9.4.6 Equipment Required

The GSE (shown in Table 10-2) will be required to support the refurbishment program. The quantities listed are required to support a 90 percent refurbishment rate; however, since refurbishment rate is unpredictable until after the first few recovery cycles are complete, the same items will be stocked for lesser recovery and refurbishment rates.

10.9.4.7 Manpower Required

The manpower requirements shown in Tables 10-3 and 10-4 are for the refurbishment operations aboard ship, on the dock, and in the RISS building. It is assumed that crane personnel from other operations will be available to assist in refurbishment operations.

TABLE 10-2
REFURBISHMENT EQUIPMENT
(156 IN. PARALLEL)

	<u>40/yr</u>	<u>60/yr</u>
Pin puller	4	4
Chocks	20	20
Lifting device, empty case	1	1
Bridge crane	1	1
Lifting slings	1	1
Lifting device, nozzle	1	1
Semitrailer	1	1
Tractor	1	1
Chocks and tiedowns	1	1
Grit blast facility	1	1
Paint sprayer	1	1
Degreaser	1	1
Forklift truck	2	2
Work platform	2	2
New facility bldg, 10,000 sq ft		
Overhead crane, 15 ton	1	1
HPU shipping chocks and cover	8	12

TABLE 10-3

MANPOWER REQUIREMENTS, REFURBISHMENT
AT 90 PERCENT RATE

<u>Personnel</u>	<u>GTM & FTM Direct</u>	<u>Production</u>			
		<u>10/yr Direct</u>	<u>20/yr Direct</u>	<u>40/yr Direct</u>	<u>60/yr Direct</u>
Packaging man	1	1	1	1	1
Liaison engineer	1	1	1	1	1
Truck driver			1	2	2
Mechanic/welder	1	1	1	2	2
Inspector	1	1	1	1	1
Crane operator	1	1	1	2	2
Operator	4	4	4	8	8
Leadman			<u>1</u>	<u>2</u>	<u>2</u>
	9	9	10	17	17

Assumptions: Operations will be performed on a one crew, one shift basis
with overtime as required.

TABLE 10-4

MANPOWER REQUIREMENTS, REFURBISHMENT
AT 50 PERCENT RATE

<u>Personnel</u>	<u>GTM & FTM Direct</u>	<u>Production</u>			
		<u>10/yr Direct</u>	<u>20/yr Direct</u>	<u>40/yr Direct</u>	<u>60/yr Direct</u>
Liaison engineer	1	1	1	1	1
Truck driver				1	1
Mechanic/welder	1	1	1	1	1
Inspector				1	1
Crane operator	1	1	1	1	1
Operator	4	4	4	5	5
Leadman	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>
	8	8	7	11	11

Assumptions: Operations will be performed on a one crew, one shift basis with overtime as required.

10.10 ALTERNATE CONFIGURATIONS

10.10.1 156 Inch Diameter Series Configuration

Transportation, handling, assembly, and checkout of the components required in the 156 in. diameter series alternate will not vary greatly from the parallel configuration. The motor segments will be handled and transported in the same manner. The SRM's will be assembled in essentially the same way. The same checkout and testing procedures will apply.

The main differences in this configuration will be in manpower and quantities of equipment required for the higher launch rates. The manpower required to support these launches are as shown in Table 10-5.

10.10.2 120 Inch Diameter Parallel Configuration

Transportation, handling, assembly, and checkout of the components required for the 120 in. diameter configuration is similar to the analysis for the 156 in. diameter parallel configuration. Slightly more subassembly can be performed prior to the shipment to the VAB. Manpower, equipment, and facilities will be affected slightly due to the increased quantity of components to be handled and assembled. Manpower requirements to support this configuration is shown in Table 10-6.

10.10.3 260 Inch Diameter Series Configuration

Transportation and handling of the 260 in. diameter motors has been demonstrated with an empty case. Several study programs conducted previously indicate that a large gantry crane is the only item beyond current state-of-the-art that would have to be developed. The loaded SRM monolithic case would be transported via barge to the KSC. A large mobile gantry crane (2,000 to 2,500 ton capacity) would be used to lift the motor onto and off the barge. The motor would be rotated from the horizontal position as received on the barge to a vertical position using the mobile gantry and a breakover pit/stand. The motor would be positioned and aligned on the mobile launcher using the mobile gantry. Buildup of the Space Shuttle would then occur.

Checkout of the motor would be similar to the checkout of the assembled 156 in. diameter parallel configuration. The manpower requirements to support the 260 in. diameter series launches are as shown in Table 10-7.

TABLE 10-5

MANPOWER REQUIREMENTS (156 IN.
SERIES REFURBISHMENT)

<u>Personnel</u>	<u>GTM & FTM</u>		<u>Production</u>	
	<u>Direct</u>	<u>Support</u>	<u>Direct</u>	<u>Support</u>
Test Engineer	1		3	
Data Technician	1		3	
Liaison Engineer	1		6	
Truck Driver	1		5	
Mechanic		1		6
Inspector	1		6	
Quality Engineer	1		3	
Crane Operator	1		8	
Operator	3		34	
Safety Engineer		1		3
Leadman		1		5
Field Engineer		1		2
Office & Administration	—	2	—	3
Total Personnel	10	6	73	22

GTM assumptions: Operations will be performed on a one crew, one shift basis with overtime as required.

Production flights--three day buildup.

Assume 3 shifts per day--60 yr.

TABLE 10-6

MANPOWER REQUIREMENTS (120 IN.
PARALLEL REFURBISHMENT)

Personnel	GTM & FTM		Production			
			10/Yr		20/Yr	
	Direct	Support	Direct	Support	Direct	Support
Test Engineer	1		1		1	
Data Technician	1		1		1	
Liaison Engineer	1		1		2	
Truck Driver	2		2		2	
Mechanic		1		1		2
Inspector	1		1		2	
Quality Engineer	1		1		2	
Crane Operator	2		2		2	
Operator	5		5		9	
Safety Engineer		1		1		1
Leadman		1		1		2
Field Engineer		1		1		1
Office & Administration		2		2		2
Total Personnel	14	6	14	6	21	5
					42	16
						75
						22

GTM assumptions: Operations will be performed on a one crew. one shift basis with overtime as required.

Production flight--Three day buildup.

Assume 3 shifts per day--60/yr.

Assume 2 shifts per day--40/yr.

Assume 1 shift per day--20/yr and 10/yr.

TABLE 10-7

MANPOWER REQUIREMENTS (260 IN.
SERIES REFURBISHMENT)

<u>Personnel</u>	<u>GTM & FTM</u>		<u>60 Yr</u>	
	<u>Direct</u>	<u>Support</u>	<u>Direct</u>	<u>Support</u>
Test Engineer	1		3	
Data Technician	1		3	
Liaison Engineer	1		6	
Truck Driver	2		8	
Mechanic		1		6
Inspector	1		4	
Quality Engineer	1		3	
Crane Operator	2		4	
Operator	3		15	
Safety Engineer		1		3
Leadman		1		3
Field Engineer		1		3
Office & Administration	—	2	—	3
Total Personnel	12	6	46	17

GTM Assumptions: Operations will be performed on a one crew, one shift basis with overtime as required.
Production Flights: Three day buildup, assume three shifts per day--60 yr.